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# EARTHWORK IN RAILWAY ENGINEERING

BY

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# PREFACE

THE purpose of this book is to describe in a practical manner the underlying principles which control earthwork undertakings, so far as they relate to general railway work.

It has not been possible in the limited space available to deal fully with certain matters and preference has been given to the points more directly affected by the actual constructional work.

In view of the uncertainty of the character of the material to be met with, no hard and fast scheme of operations can be adhered to, and the methods of procedure hereinafter referred to should be taken more as a guide to what course or design to follow.

The author would emphasize the importance of thorough consideration being given to drainage works, and matters relating thereto have been given special attention.

The particulars in regard to constructional work are for the most part the result of experience gained by the author when acting as Resident Engineer under Mr. Donald A. Matheson, formerly Engineer-in-Chief, now General Manager of the Caledonian Railway, and he takes the opportunity of placing on record his appreciation of the valuable assistance received from him.

J. W. F. G.

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# EARTHWORK IN RAILWAY ENGINEERING

## CHAPTER I

### PRELIMINARY INVESTIGATIONS AND ESTIMATES OF COST

The location of a railway is for the most part governed by geographical considerations, but the promoters of the undertaking will look more to the proposal from a financial point of view, and in their deliberations they will be guided by the Engineer as to the practicability and probable cost of the work.

Various proposals will no doubt have to be examined before the scheme which is to be carried out is decided upon, and, in view of the importance attached to the Engineer's report, it is essential that he be thoroughly informed in all matters which may influence the decision of his clients.

While none of the proposals which are considered may be altogether impracticable, yet the carrying out of the project may only be done at a loss. It is impossible to foresee all the difficulties that may be met with during the progress of a particular work, but these may be very considerably reduced by more particular examination of the details of the project by the Engineer when the scheme is being developed.

It has been truly said that "It is much easier to make an expensive railway than a cheap one under the same circumstances, and the object of every Engineer ought to be as far as possible to adapt the work he has to design to the results to be obtained." In a through main line of railway, heavy works such as tunnels and large bridges will in all probability require to be executed in order

avoided, and large expenditure may be justifiable, whereas, in the case of branch or secondary lines, the Engineer may have to be content with steeper gradients and sharper curves if he is to keep the cost within moderate limits. Consideration of each different project must, however, be governed by the particular circumstances of the case. What may be an economically constructed railway in one place, may be a wasteful expenditure in another.

Questions relating to location which are affected by traffic working do not fall to be considered here, and the preliminary investigations which are referred to deal with matters affecting the actual execution of the work.

The estimated cost of the works which the Engineer prepares should represent to a nearness what the ultimate expenditure will be.

The first cost of a railway may be reduced by making a detour, but, on the other hand, the annual outlay in maintenance or working of the railway may be increased in consequence of the additional length to such an extent that no real saving will be effected. The expediency of making a diversion may arise from a desire to avoid interference with valuable property, or to save the expense of the construction of a large bridge, tunnel, river diversion, or other important work, or it may be that the materials likely to be met with in the cuttings or under the site of the embankments are of a treacherous character, or the cost of the earthwork may be excessive. These, and other circumstances, may have so added to the initial estimated cost of the shorter route as to make a diversion imperative, and it should be further noted that the more heavy the description of the work the greater generally is the after cost of maintenance.

When considering whether the works should be constructed for

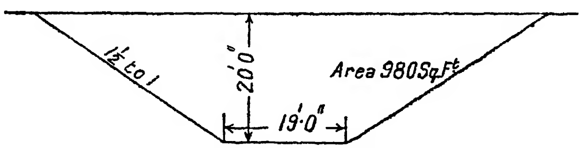



FIG. 1.—Cutting for single line.

a single or double line of railway or of a greater width, it should be kept in view that the cost of the earthwork is not proportionate to the number of lines of rail-

Referring to Figs. 1 and 2 the areas of sections for a cutting 20 ft. deep and with the usual side slopes for soft material are for single and double lines 980 square feet and 1200 square feet respectively, the increase of the double over the single line section being

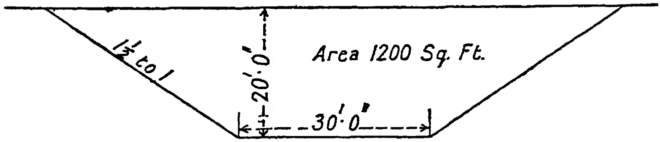


FIG. 2.—Cutting for double line.

about 22½ per cent. This increase is represented in Fig. 3 by a vertical strip 11 ft. wide, and roughly indicates the increased cost of the earthwork with cuttings and embankments of an average depth of 20 ft. for a double line of railway over a single line of railway. The excavations for the greater width would cost a little

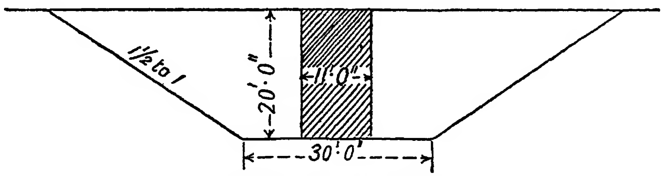


FIG. 3.—Difference between cutting for single and double lines.

less per unit of volume on account of the service roads and other temporary works and plant required during construction not being proportionately increased, and also on account of there being greater facilities for carrying on the operations, but for all practical purposes the same unit rate may be used in preparing the preliminary estimates of cost.

If there is a likelihood of the railway being widened at some future time it may be advantageous to acquire land for the wider line to begin with, although the construction of the wider line may be deferred to a future date.

In the construction of the partial scheme the quantity of materials in the cuttings may be in excess of the quantity required to form the embankments, and the surplus excavated

widening, or for station yards which may be contemplated in the future, if these are conveniently situated to the cuttings.

In fixing the width of formation regard must be had to the future maintenance of the railway. The additional cost of constructing cuttings and embankments a foot or two wider so as to obtain better drainage in cuttings and greater solidity in embankments is small compared with the extra periodical expenditure in maintenance incurred by the construction width being restricted. By increasing the width of a double line cutting 20 ft. deep and in ordinary soft material from 28 ft. to 30 ft., the quantity of excavations is increased by only 3½ per cent. The advantage of having sufficient width of formation is referred to in Chapter VII, page 130.

Consideration must also be given to the curves and gradients of a railway. With a diverted or longer route, better gradients may be obtained than with the direct route, but with the latter there will probably be a better alignment. These matters will require to be considered from a traffic working point of view before the route is finally decided upon.

In settled countries there is not the same opportunity for railways being made on constructionally economic lines on account of the proximity of valuable land and property, but in undeveloped countries where land is either given free or is comparatively cheap considerable attention is now being paid to the question of economics in construction which will undoubtedly effect large savings in carrying out the undertaking and also give a better return for the capital expended.

In laying out the line of a railway or road, endeavour should be made to reduce the quantity of earthwork to a minimum, and the formation level should, consistently with other considerations, be fixed so that the quantity of suitable material excavated from the cuttings will just be sufficient to form the embankments. It must be kept in view that all unsuitable materials should be run to spoil and allowance also requires to be made for the quantity of excavations which may be used for constructional purposes. It is a considerable advantage to have the "lead" (haul) to embankment on a down grade and as short as possible.

The cost of the work, as will hereafter be shown, is largely

Under certain conditions it may be advantageous to run some of the materials which are quite suitable for embanking purposes to spoil embankment rather than run them for a considerable distance on an up grade. To make up the deficit of embanking materials thus caused, side cuttings or borrow pits may be necessary, and while this would incur the additional cost of excavation it may be a cheaper method to adopt. Where furnace ashes can be obtained in large quantities and at little cost no better material could be obtained for making an embankment and the work of depositing them can be carried on very speedily. An embankment constructed of ashes will also entail a minimum of expense in subsequent maintenance.

The site of a spoil bank should be convenient to the excavations and have an easy access with a minimum of expenditure for wayleave, use of ground, subsequent restoration and for depositing the material. A mistake may be made by using moss land or other similar site where the ground can be cheaply obtained, as there may be considerable expense incurred in making up and constantly repairing service roads while the material is being deposited.

The simplest construction for a railway might appear to be where the work is executed on side-lying ground, partly in cutting and partly in embankment, and with just sufficient material in the cutting to form the embankment. If the material excavated is of an earthy description and can be removed without any slipping on the upper side taking place the conditions would be favourable, but if, on the other hand, there is a tendency for the ground to slip by reason of the support which formerly existed having been removed, the work may be very costly to execute. This matter is fully considered in subsequent reference to slips.

In skirting hillsides it is frequently found that the natural slope of the soft material overlying rock is inclined at the angle of repose of the material, and it is thus desirable under these conditions to have as little cutting as possible. The material necessary for embanking purposes could then be obtained either from adjoining cuttings where the surface was at such an angle as to prevent slips or it could be got from borrow pits. In the latter contingency the extra cost of side cutting would be incurred, but this course may ultimately prove to be the more economical form of construction.

to dispense with cuttings almost entirely and thus avoid obstruction to traffic by snow blocks, the banks being made up by material taken from borrow pits. Apart from the question of snow blocks a railway on embankment is less costly to maintain.

The side ditches in a cutting require to be kept clear of materials washed off the slopes or which may have collected, and which if not removed will tend to keep the formation of the railway in a wet sodden condition, to the detriment of the permanent way.

In countries where timber is plentiful, ravines necessitating what would be long high embankments may be temporarily spanned by trestle-work so as to speedily complete the line of communication, and at a later date the embanking materials would be deposited.

Again, by following closely the line of a water-course the presence of moss, clay, or other soft material may be the cause of serious trouble, either in a cutting or in an embankment, and therefore the possibility of more material being excavated or more material being required for embankment than originally anticipated should not be overlooked when locating the proposed works.

In rough hilly country, where there may be a large exposed surface of loose friable rock and boulders, the streams will, after frost and during torrential rain, carry in their course a considerable quantity of stones down the hillside which will be deposited on the plain below.

If the railway were constructed on the flat land at the foot of the hill, any water openings would then be liable to be choked up, and the railway should, therefore, be constructed on the hillside where the velocity of the water is still great enough to carry the stones through the water openings.

Further, the water-courses which are confined to narrow channels on the hillside will open out and spread over a wide area on the flat ground, which in flood-time will thus be under water, and if the railway were constructed on the low ground considerable damage might result before the water passed through the flood openings in the railway embankment. Reference to allowing flood water to pass entirely over low railway embankments is made in Chapter III, page 21.

The cost of the undertaking will largely depend on the character of the materials met with during construction, and it is necessary

For the purpose of the preliminary estimates, this information will have to be obtained from general observations of the surrounding country, and from geological maps of the district, if these are procurable. In the absence of actual bores or trial pits on the site of the works, the depth of soft material overlying rock and the characteristics of that material would be more or less indefinite, but after such arrangements have been made as will allow of a complete series of bores being taken or trial pits sunk, the fullest particulars should be obtained.

The cost of obtaining information in regard to the strata is so small in comparison with the results obtained that in work of any magnitude the question of expense should be a secondary consideration.

The extent of land necessary for both cuttings and embankments is dependent upon the character of the materials in the cuttings and under the sites of the embankments. If the works are being constructed through or in the vicinity of valuable property retaining walls may be required to support the sides of a cutting, or reduce the area of land covered by embankment, and the cost of these contingent works has also to be estimated.

The Engineer must keep in view the possibility of the materials requiring flatter slopes than would at first sight appear necessary and the probability of retaining walls having to be provided to retain the slopes within the land acquired or the necessity of more land being required than was originally contemplated. If more land has to be bought after the works are commenced a larger rate will most likely have to be paid for it. If these matters are lightly passed over the original estimates will in all likelihood be largely exceeded when the works are completed.

In the initial stages of an undertaking it is generally necessary that secrecy be observed, and, in view of this fact, and also on account of the short time usually allotted for the preparation of preliminary enquiries, the estimates of cost may be of a somewhat incomplete description. An exact section of the ground may not be available, but sufficient information can generally be obtained from "spot" levels of the more prominent points, and by making full use of the levels and contour lines which are laid down on Ordnance Survey maps. For the purpose of calculating the quan-

required typical cross sections should be prepared, and in open country these might be at intervals of from three to five chains apart.

In view of the approximate description of the preliminary estimates an ample allowance—say 10 to 15 per cent of the whole—should be added to the cost for possible contingencies, so that the total sum will prove adequate for the execution of the proposed work. It is better that this estimate should be over rather than under the actual cost of the undertaking, so that the promoters of the scheme will not be misled, but unfortunately it too frequently occurs that preliminary estimates are considerably understated.

Where estimates of costs are subjected to the criticism of rival Engineers or Parliamentary Committees, and when the various details on which the figures are based are subjected to the closest scrutiny, it is most desirable that the assumptions both as regards quantities and rates should be well founded.

After Parliamentary sanction has been obtained or agreements have been made with the proprietors of the land on which the proposed works are situated, complete longitudinal and cross sections of the ground should be taken and a thorough investigation made of the strata so that the exact line of the railway may be determined and a fully revised estimate of cost prepared. The quantities of the materials of this new estimate will form the basis for the subsequent Contract Schedule and these should be as full and complete as possible. Special consideration should be given to the unit prices for each item of work. The probability of an increase of the cost of labour or materials during the period of construction and the possibility of interruption by reason of wet weather and consequent loss should also be kept in view.

The magnitude of the work will also influence the unit cost. In works of small dimensions on which it would be unprofitable to place large and expensive plant the cost would be proportionately more than where mechanical excavators, etc., can be advantageously used. The more complete the information is that affects the quantities or prices the nearer will be the amount of the Contract Tender to the actual cost of the work, in which case the result will be more satisfactory to both contracting parties.

# CHAPTER II

## INVESTIGATION AS TO STRATA

IN earthwork undertakings the principal matter that affects the quantities and prices in the Detailed Estimate on which the Contract Tender is based, is the character of the strata under the site of the works.

It is thus of the first importance that definite and reliable information be obtained in regard to the characteristics of the materials in the strata. The presence of water and the effect of it on the various classes of materials met with have an important bearing on the success of the undertaking, and particulars relative thereto should receive special attention.

For the purpose of ascertaining the character of the strata it is usual to put down bores along the line of the railway or over the site of the works.

Some Engineers consider that trial pits should be sunk, so as to get more complete information than is obtainable from bores.

By the particulars so obtained the slopes for the cuttings are decided on and the quantities for the Contract Schedule calculated.

The slopes in a cutting of ordinary material may vary from 1 horizontal to 1 vertical, to 2 horizontal to 1 vertical, while in a rock cutting from a plumb face to ½ horizontal to 1 vertical, depending on the character of the material, the quantity of water met with, the effect of water or atmospheric conditions on the material when exposed, and the slope or "dip" of the strata.

A description of the materials on the sites of the embankments is also essential for the purpose of ascertaining the bearing capacity, and fixing the quantity of material required for the embankments.

If in carrying out the work there should be any great divergence in the actual quantities of materials in the cuttings from what was stated in the Contract Schedule the method of procedure may have to be modified.

As example, a cutting may contain considerably more rock than was at first anticipated, and on account of this it may be necessary to construct overland routes for the purpose of passing the material from other cuttings to embankments, and thus allow the operations in the soft cutting to be proceeded with at the same time as in the rock cutting, or other special means may require to be adopted so that the work may be executed within a reasonable time.

The fact of having an increased quantity of rock to excavate increases both the cost of the work and the time of completion and if definite information in regard to the strata had been forthcoming previous to the work having been commenced the Engineer might have considered a diversion of the route of the railway, or the promoters might have decided to abandon the project.

When executing the widening of an existing railway it may seem sufficient to form an opinion as to the character of the materials in cuttings from the appearance of the existing cuttings.

In the case of solid rock cutting no mistake may arise, but in the case of the ordinary soft material or materials of a "faikey"* character where the action of the weather may have very materially altered the adhesion of the particles or the surfaces to one another, it is not safe to rely too much on what is seen of the existing cuttings.

In a case which recently came under the author's notice the slope of the original cutting had a batter of $1\frac{1}{2}$ horizontal to 1 vertical, and to all appearance the cutting was of a clayey description. On executing the work, however, the material met with consisted of close-bound gravel held together by hard clay, and was of such a character that it was quite impossible to remove it by pick and shovel. On account of the situation it was not possible to use a steam digger, and it was necessary to break up the material by blasting throughout the whole period of the operations. After the material had been exposed to wet weather the clay lost all its cohesion and the slopes had to be dressed to the batter for an ordinary soft cutting. At several places in the slopes minor slips took place on account of the "weathering" of the material.

In another instance of railway widening a number of large pieces of rock protruded from the slope of the existing cutting, which gave every indication of rock being met with, but on the work

* Similar in character to laminated shale.

being carried out it was found that no solid rock existed and that a large number of loose stones were embedded in the slopes of the old cutting, so that the appearance of the original cutting was deceptive in respect of the actual condition of matters.

In general practice boring is carried out by means of a chisel, samples of the material passed through being brought to the surface for inspection at intervals as the sinking operations proceed. Where more accurate information is required diamond drilling is adopted, in which case a solid core of the material passed through is obtained.

By sinking pits the most reliable data as to the actual state of matters will be obtained, but the time taken in sinking pits of any great depth will, in most cases, be against this mode of procedure.

Chisel boring is a very simple operation, and when the work is in the hands of a thoroughly skilled and trustworthy borer very satisfactory results are obtained.

In chisel boring, owing to the importance of the information required, the work should be carried out by a reputable firm of borers under the direct supervision of the Engineer, who should keep himself fully conversant with the progress of the operations, and have repeated checks made of the depths of the strata entirely independent of the journal with which the borer afterwards furnishes him. He should also verify the depth of each bore immediately after it has been put down to the required depth. The borer should lay out for inspection samples of all the various strata passed through. By adopting such means the information so obtained will be as accurate as is possible by this method.

It is unnecessary to describe in detail the whole procedure of chisel boring, and only a brief reference to the tools and the manner of use will be made. The bore hole is formed by repeated blows from a chisel (*c*) which is raised and lowered by manual labour (see Fig. 4). The tool is turned round in the hole a quarter of a circle after each stroke is made so that no two blows fall in succession on the same spot, and the material, after being thoroughly bruised, is brought to the surface by means of a "sludge" pump (*f*).

In passing through ordinary soil, sand, clay without stones, or similar material the sharp edge of the tube of the pump is sufficient to pierce the strata, but where gravel, boulders, or

rock are met with the chisel is required. Where the material is exceptionally hard the cross-shaped piece, or "riffle" tool (*e*), is used.

The cutting tool is connected with the cross-head on the working platform by means of 1-in. square section rods, which

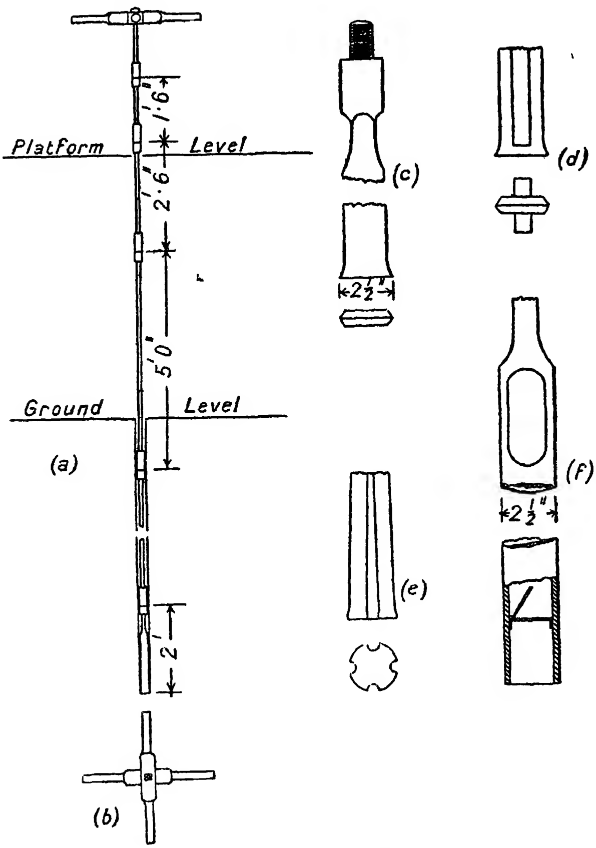



FIG. 4.—Chisel boring.

are generally in lengths of 5 ft. and screwed together as shown; shorter lengths being used when each of the 5-ft. lengths has brought the cross-head down to the level of the working platform. The platform should be at a height of about 5 or 6 ft. above the ground so as to allow of tubing being inserted into the bore holes

when passing through soft ground and where the sides of the hole would have a tendency to fall in unless properly supported, in which case an inaccurate record would be obtained. It is necessary that the tube should closely follow the cutting tool as the work proceeds. Of course, in rock no tube lining is necessary.

If the strata should be dry it is essential that water be poured down the tube for the purpose of converting the material into a consistency of slurry and thus allow of it being removed by the "sludge" pump. In order that a correct record may be obtained samples of the strata should be brought to the surface at least every 2 ft. of depth.

All depths should be measured from the level of the working platform, the height of which above the level of a wooden peg or mark on the ground level should be known before boring operations are commenced. The level of the peg or mark should be connected with Ordnance Survey level or the same datum to which the sections for the railway have been taken, so that after the journal of bores has been completed the information obtained can be laid down on the sections of the ground surface. Three or four men are usually employed in sinking the bore, one of them being a practical borer who would be responsible for the preparation of the record. While the contents of the "sludge" pump indicate the character of the material passed through, the borer puts considerable reliance on the "feel" on the cross-head.

When boulders are met with, if the boring tool comes down fair on the top of the stone, there will be no difficulty in passing through it, but if the tool strikes the smooth rounded surface away from the top, the stone will yield in the surrounding clay and it will be next to impossible to pierce it. In such case a small charge of dynamite should be inserted in the bore and the boulder shattered. If this is not effective it will be necessary to abandon the bore and sink another a short distance away.

All the bruised material, whether hard or soft, is brought to the surface in the same wet condition, and it is only by the "feel" when sinking and the rate of progress that the relative hardness of the material is ascertained. It is necessary that the pump be put down at every 2 ft., and more frequently if necessary, if a change of stratum is suspected by the "feel" on the cross-head. It will

be recognized that the borer, in addition to having a thorough practical knowledge of his business, must exercise considerable care in systematically noting the various changes of material if the results obtained are to be of any real practical value.

A very common error, and one which has frequently been the cause of much litigation, is to mistake a boulder in a "soft" stratum for solid rock. The effect of this may be very serious. In the case of a railway or road cutting, by assuming that rock has been reached when only a boulder has been struck the quantity of material which it is anticipated has to be excavated may, as already stated, be considerably in excess of the actual quantity to be removed and this may have serious consequences.

When rock is met with, before it is recorded as solid rock, the thickness passed through should exceed 5 ft. If this depth is exceeded it is pretty safe to assume that a bed of rock has been passed through, but if not, a new bore 6 or 8 ft. distant should be put down as a check, and if the strata is repeated it is evident that a layer of rock exists. The depth of a bore hole should never be less than 5 ft. below the bottom of the proposed excavations, whether in "soft" or in "rock," so that the fullest information may be obtained of the material to be excavated and also of the character of the strata below formation level of the railway on which it is proposed to support the foundations of structures.

Hard-bound gravel can be easily distinguished from loose gravel and the various degrees of hardness of faikes and limestone can also be easily recognized, and where water is in a strata its presence can be detected. The volume of this water—a point which is of very great importance when carrying out constructional work—cannot, however, be computed by boring.

As regards diamond boring, this method is now generally adopted where it is of advantage to have a solid core of rock, such as in mineral prospecting, and in locating the site of a reservoir embankment, where it is of great importance to know the character of the stratification below the submerged area. In the case of tunnel work, or where heavy foundations are in rock, the results obtained from diamond boring would be preferable to those obtained by chisel boring. The result of the bore cannot be questioned when a solid core of rock can be seen, and the consequent risk of error in judgment on the part of the borer is thereby eliminated.

In diamond boring the material is cut through by abrasion instead of by percussion, as is the case in chisel boring.

The cutting tool or "crown" consists of a mild steel cylinder on the lower surface of which carbonados (imperfectly crystallized diamonds) are studded at intervals (see Fig. 5). When the bore is being taken for mineral prospecting or for the purpose of ascertaining the character of the strata for earthwork operations the core of rock need not be more than 2 or 3 in. in diameter. The "crown" piece would be about ½ in. thick and a set of twelve diamonds is distributed over the lower, outer, and inner surfaces, as shown on the diagram, so that the bore hole which is formed will be slightly greater in diameter than the cylinder in which the diamonds are set, and the core of rock which is cut out will be slightly less in diameter than the internal surface of the cylinder. The diamonds are so arranged that the ring of material cut through between the outer and inner edges of the cylinder will be entirely crushed.

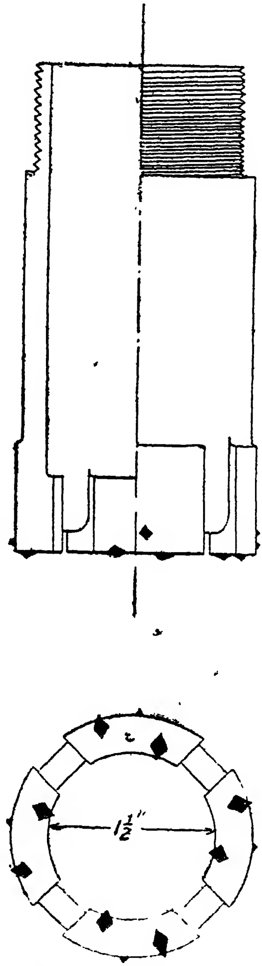


FIG. 5.—"Crown" of diamond drill.

The core, after being cut, passes up through the "crown" cylinder into the core tube, which is about 6 ft. long and which is screwed on to the upper end of the cylinder. This tube in turn is attached to hollow iron rods of convenient length which extend to the surface of the ground. The tool is caused to revolve either by hand labour or by being connected to a stationary engine.

It is necessary while the boring operations are in progress that a constant and ample supply of water be forced down the hollow rod and through the core tube so that the crushed material under the cutting edge will be immediately

washed out, the water rising up the outside of the core tube and flowing over the bore hole. The water also assists in keeping the cutting tool cool. The tool is caused to revolve at a speed of from 60 to 100 revolutions per minute, depending on the character of the materials passed through.

It is most important that the crushed material under the cutting edge be instantly removed, as otherwise the metal in which the diamonds are fixed will become worn and the diamonds will drop out. The pressure on the rock under the cutting edge should be relieved as the work progresses by having a back balance weight fixed to a cross-head at the surface.

While diamond boring gives the true character and exact thickness of the various beds of rock passed through, it is not possible to say in which direction the rock is dipping, but by taking a series of bores a correct geological section can be prepared.

### TRIAL PITS

Trial pits would be 5 or 6 ft. square. If the excavations are soft material it would, unless the pits are comparatively shallow, be necessary to close timber the sides of the openings. If the stratum is rock, timbering would not be necessary. Operations would be retarded if water were met with, and if it should be of considerable volume it may be impossible to proceed with the work. In bad ground or where there is a large volume of water iron cylinders, consisting of built segmental sections with flange joints, would be used.

While the time occupied in sinking trial shafts is considerably more than that taken by putting down bores, the information obtained gives a more correct indication of the strata passed through. Trial shafts at intervals supplemented by a series of bores to ascertain the levels of the various beds and thereby find out if there is any exceptional variation in the strata would provide a full knowledge of the geological conditions.

Trial shafts or bores are of no practical value unless they are carried down to the full depth of the proposed excavations, or, in the case of foundation work, to the depth of a solid stratum.

As regards the rate of progress in boring, the following figures give a rough approximation :—

WITH HAND CHISEL BORING

| | |
|---|---|
| Fine sand or clay without stones | 50 ft. in 8 hrs. |
| Boulder clay or open gravel | 20 ft. ,, |
| Close-bound gravel | 6 to 8 ft. ,, |
| Soft sandstone | 8 to 12 ft. ,, |
| Hard sandstone | 2 to 4 ft. ,, |
| Extra hard sandstone | 1 ft. ,, |

WITH DIAMOND BORING

| | |
|---|---|
| Hard sandstone | 10 ft. ,, |
| Extra hard sandstone | 5 ft. ,, |

When hard whin boulders are met with in boulder clay it is no uncommon thing for only a few inches to be pierced by chisel boring in a day's work.

While the chisel is the tool generally in use for boring in this country, the "wash-out" drill, which, as the name implies, consists of the material being washed out by water under pressure, is largely used in America. The record so obtained in passing through soft material is not considered very satisfactory, but the advantage in using this system is the rapidity in clearing a way for a diamond drill being used in the rock underneath.

In describing the strata passed through a Borer should refrain from making use of any local expression which may be ambiguous or misleading, and the Engineer, when preparing the journals which are to be shown to, and will be made use of by, the Contractor, should make certain that the description which he gives is in general terms and correctly sets forth the class of material so that no subsequent misunderstanding may arise as to the character of the materials in the bore.

While it may not be absolutely necessary for a Borer or an Engineer to have a knowledge of geology there is no gainsaying the fact that only by a thorough appreciation of the characteristics of the materials generally met with and their relative positions to one another in the strata, together with the conditions under which they have originally been deposited, can he form a correct opinion of the materials he is dealing with.

# CHAPTER III

## CULVERTS AND DRAINAGE

The situation of a line of railway, relative to rivers and principal waterways, is an important consideration in determining the location of the proposed works. The larger rivers and waterways would be crossed by means of bridges or viaducts, and do not come under the present investigation.

In crossing streams or water-courses of less magnitude the provision which requires to be made must receive due consideration in designing and carrying out the works. Local deviations of the line of the railway may suggest themselves with a view to less costly, while equally efficient, conduits or culverts being constructed without materially affecting the cost of the earthwork or other works. These may result in a shorter length of waterway or in a more solid foundation being obtained, or what is of considerable importance during construction, a line may be got which will allow of the greater part of the operations in constructing the waterway being executed with a minimum of interference with the original water-course, and thereby in comparatively dry ground.

By taking the water channel whether in tunnel or open-cut through a spur of rock the excavations may be more costly to execute, but by reason of a shorter length of channel being obtained less masonry will be required for facing the excavations and in constructing the arch and invert, and the total cost may thereby be considerably reduced.

It is of the utmost importance when making a railway that all work connected with the construction of culverts or waterways, or the drainage of the adjoining lands, be entirely completed before the earthworks in the vicinity are proceeded with, so that slips, by reason of water flowing through the strata into the cuttings or under the site of the embankments, may be reduced to a minimum.

The capacity of a culvert or waterway should be such as will

allow of the free passage of water during the period of maximum rainfall. Careful observations should be taken of the flow in the stream during wet seasons and flood-times and information should also be obtained from old residents in the district. By comparing these particulars with records of rainfall taken during previous years, if such are available, an approximate idea of what may be expected will be obtained. Where there are existing culverts or bridges on the streams which are being dealt with the effect of the flow of water on these and their capacity to deal with the quantity of water passing through them should be noted.

Apart from any information so obtained it is desirable that the size of the culvert required to carry important streams under the railway should be ascertained by calculation. The determining factors are, the maximum rainfall in the district, the area of the water-shed, the slope of the ground from which the water discharges, the porosity of the soil, and the condition of the stream or river bed. Various formulæ are in use, but it will be recognized that the local conditions referred to make a universal application of a formula for the "run-off" impracticable.

There will be a much greater discharge from an area with steep sides than from a flat basin. The more impervious the surface of the ground is the greater will be the discharge, but it should be borne in mind that some soils will be rendered impervious after a few hours' heavy rain, at the end of which time the soil may be said to be water-logged. A wet marshy ground might be described as water-logged and will yield a large "run-off" in a heavy rainstorm.

A good formula for ascertaining the discharge from catchment areas, given in Parker's "Control of Water," is :—

$$Q = 640 \text{ F.I.M.}$$[1]

Where :—

$Q$ = discharge in cubic feet per second.
$I$ = Average intensity of max. rainfall in inches per hour during a period of time equal to that taken by the flood water to reach the culvert from the farthest point of the drainage area.
$M$ = Area of catchment area in square miles.

F is a coefficient depending on the character of the surface as follows :—

For flat country, sandy soil, or cultivated land, 0·25 to 0·35.
For meadows and gentle slopes, 0·35 to 0·45.

[1] This formula is sometimes given: $Q = 640\,F\,\sqrt[4]{(I^3)}\,M$.

For wooded hills and compact or stony ground, 0·45 to 0·55.
For mountainous or rocky ground, or non-absorbent (e.g. frozen soil) surfaces, 0·55 to 0·65.

Apart from the results obtained by the use of a formula an ample margin should be provided for extraordinary floods. Some Engineers double the result obtained by a formula, and in view of the damage which may result from having a restricted waterway and the small increased expenditure incurred in providing the larger culverts as compared with the cost of the whole railway undertaking this seems a proper course to adopt.

The late Dr. Deacon, when investigating the rainfall in the Welsh mountains in connection with the Liverpool water supply, ascertained that the maximum discharge of tributary streams commonly reached 1000 times the dry weather flow, and occasionally individual streams very much exceeded that figure. In the Vyrnwy River, even after passing over from four to five miles of alluvial deposit, the maximum discharge recorded as much as 800 times the dry-weather flow of the river, and the records obtained from rain gauges which were within a few miles of one another showed a very considerable variation in rainfall.

It is thus most important that information regarding the flow of water in streams should be localized as much as possible, and that the capacity of the culvert should equal the discharge from extraordinary floods. The probability of there being excessive flooding by reason of melting snow should be specially noted.

Allowance should be made in designing culverts for the possibility of the effective sectional area being reduced by becoming silted up. This will be greater if the stream has a flat gradient, as under ordinary circumstances the flow in it will be sluggish.

In new countries where records of rainfall are not obtainable it is usual to construct temporary timber bridges or rail openings which are in use for a few years until it is seen what provision requires to be made in constructing the permanent culverts.

In hilly country a large quantity of embanking material is generally lost on account of sudden and heavy floods before it is possible to judge what size of openings should be provided, and the embankment on each side of these water openings should be well protected by having stone pitching carried up the slopes as high as the probable flood level.

Where there are wide depressions of land in countries subject to heavy rainstorms, over which during the period of floods a large area of flood water flows, it is usual, provided the water is shallow, to let it pass over the line altogether (see Fig. 6). This is effected

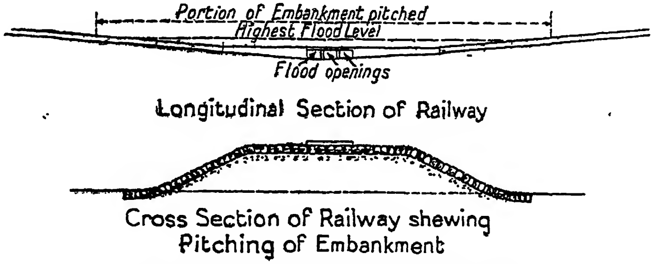



FIG. 6.—Water openings in embankments.

by forming the line on each side of the depression with an easy grade down to a level portion, which level portion might extend to from 100 to 400 ft. in length, as shown in the diagram. For the purpose of protecting the railway and the slopes on each side and between the sleepers, the surface would be covered with stone pitching which would extend for the whole length of the level portion and up the gradients to a level clear of flood level.

## DESIGN OF CULVERTS OR WATER-COURSES

It is of the utmost importance that the construction of culverts and water-courses, where they pass under embankments, should be of a most substantial description in view of the expense and inconvenience incurred in opening up embankments for the purpose of executing remedial work.

Existing conduits on the site of the embankment should be strengthened or reconstructed. When pipes are used for the purpose of carrying the stream, they should preferably be of iron or steel, and if they are not laid on solid ground they should be supported on masonry piers or piles. On account of malleable iron or steel pipes being lighter than those of cast iron they can be made in longer lengths and consequently fewer joints are necessary. They are also less liable to injury than cast-iron pipes.

In soft ground or where there is a tendency to subsidence by

reason of mineral workings malleable iron or steel pipes are preferable. The smaller weight per unit of length is also a consideration in cases where it is necessary to drag the pipes over fields or convey them long distances over secondary roads. Malleable iron or steel pipes, however, are more subject to corrosion than cast-iron pipes, and care should be taken to ensure that they are properly protected by preservative coatings or by having them encased in concrete.

Where fire-clay pipes are taken under a railway they should be

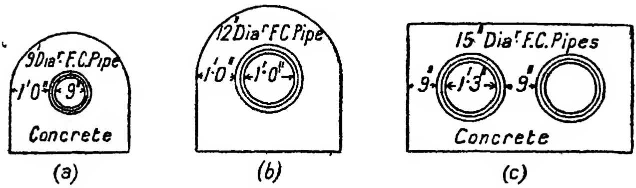



FIG. 7.—Fire-clay pipe drains under railway.

encased in concrete (see Fig. 7). When concreting materials can be economically obtained a fire-clay pipe conduit is in many cases adopted in preference to cast iron, more especially in the smaller diameter of pipes.

In conveying water from one side of a railway embankment to another when crossing bog-land, timber box drains are generally

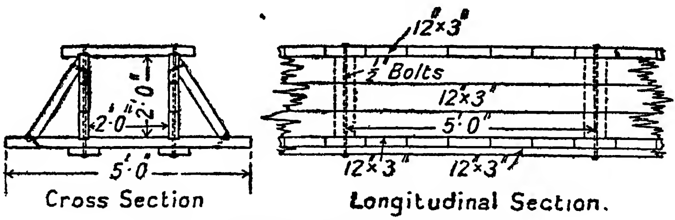



FIG. 8.—Timber box drain under railway.

used (see Fig. 8). While these may be considered to be more of a temporary character, if they are constructed of creosoted pitch-pine timber they will last for a number of years, and in the particular situation where they would be used they are easily accessible when they require to be repaired or renewed.

For conduits of a less size than 2 ft. 6 in. square, and where pipes cannot be conveniently used, built stone drains are constructed

(see Fig. 9). These consist of a floor of concrete with masonry walls built with cement and covered over with a slab or paving stone. The cover stones should be well bedded on the top of the side walls

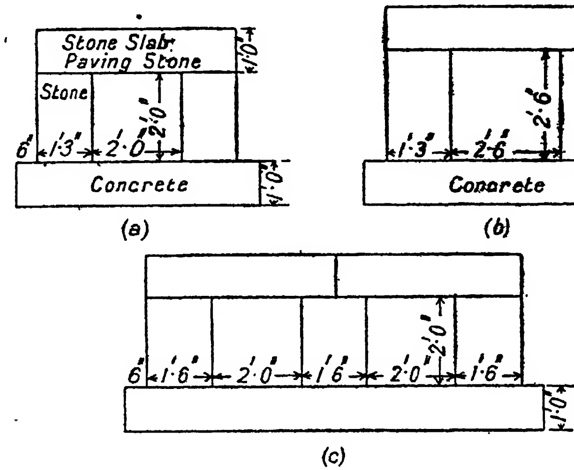



FIG. 9.—Built stone drains under railway.

and close jointed with cement mortar in order to prevent banking material finding its way into the culvert.

When the volume of water in a stream is greater than a 2 ft. 6 in.

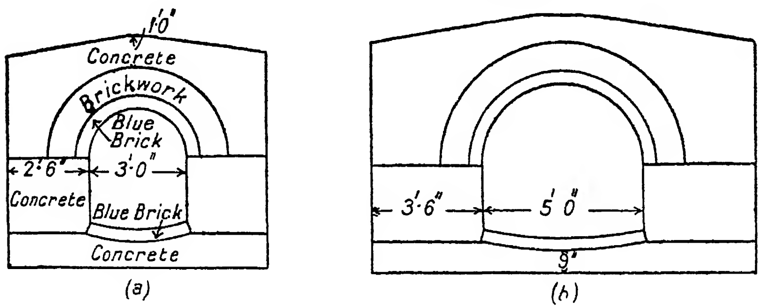



FIG. 10.—Arch culverts under railway.

drain can carry masonry built culverts are adopted (see Fig. 10). These generally have an arched roof and are either wholly of concrete or are constructed partly of concrete and partly with stone or brickwork. The particular materials used will be governed by

the facilities for obtaining them. Ferro concrete construction is now largely adopted, having either a rectangular or arched section. To ensure satisfactory results, however, it is absolutely essential that the materials used should be of the best description and also that every care be taken in the making of the concrete.

Riveted malleable iron or steel tubes are sometimes substituted for built culverts. These can be obtained up to 6 or 8 ft. in diameter, and, being accessible for inspection and for painting or coating with preservative solution, they may, if proper attention is paid to the maintenance, be said to be equally as efficient as a masonry culvert. If one line of tubing is not sufficient to carry the stream two or more could be laid alongside one another.

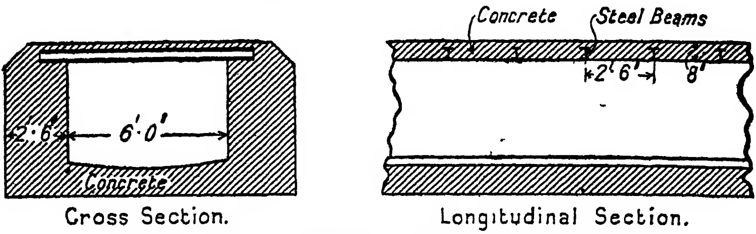



FIG. 11.—Culverts with steel beams and concrete covering.

en the headway above the bed of the stream where it passes · a railway or road is limited, the roof of the culvert could rmed with steel beams and concrete filling between them, or slabs of concrete with steel reinforcement could be used (see Fig. 11). These can either be built in lengths on the solid ground alongside and afterwards lifted into position, or the reinforced concrete can be formed *in situ* by placing timber between the side walls. The former method has the advantage that less timber is necessary, but, on the other hand, additional lifting power is required to place the slabs in position if they are made on the adjoining ground.

When a culvert requires to be constructed in very side-lying ground and where there would be considerable flow the invert should be left rough, and, in this connection, whinstone pitching is largely used. In open channels, in addition to whinstone pitching being used for the purpose of checking the flow, some of the pitching stones can be set on edge at intervals and made to project above the surface to the extent of about 6 in., the object being to further reduce the velocity of the current.

A series of steps at the end of a culvert would fulfil the same purpose, or a well or pool about 4 ft. in depth could be formed

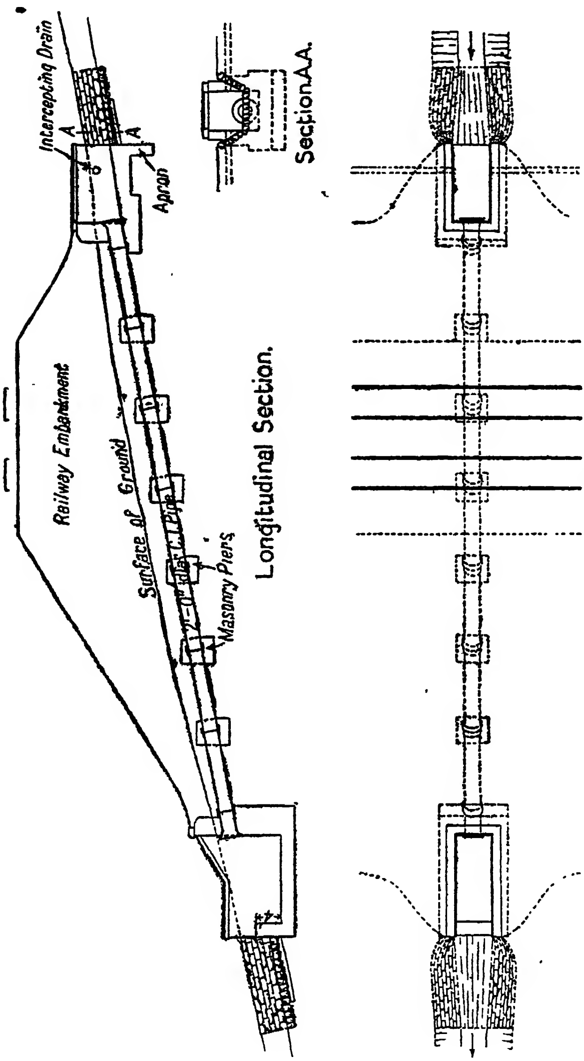



FIG. 12.—Pipe conduit under railway embankment on side-lying ground.

into which the water would discharge before getting into the regular course of the stream (see Fig. 12).

When a line of pipes is laid on side-lying ground the pipes should

be supported by small masonry piers which, in the case of cast-iron pipes, would be placed on the lower side of the faucets, or the joints can be encased in concrete, as shown in Fig. 12, while if malleable iron or steel pipes are used the pipes would be held in position by having metal straps riveted to the tubes at intervals, the ends of the straps being embedded in concrete blocks. Any movement in the pipes would be attended with very serious results to the embankment overhead.

In the case of a culvert built on sloping ground the foundations should be laid on level benches while the water-run would either follow the grade of the side-lying ground or could be stepped, and if the ground has a very steep slope the arch would also be built

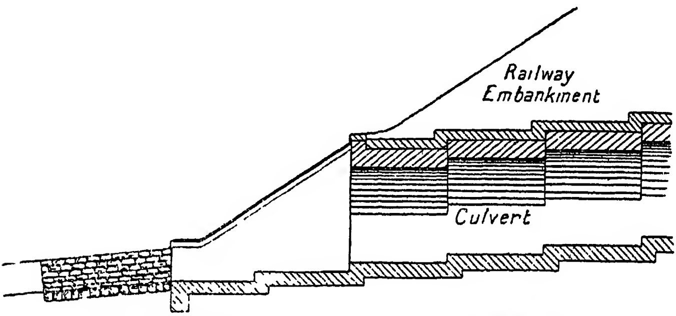



FIG. 13.—Stepped arch culvert on side-lying ground.

in level sections (see Fig. 13). The level crown, while allowing of level beds being formed in the masonry, would also act as a support to, and prevent slipping of the embankment.

Where culverts are constructed on soft ground they should be carried on piles and built in lengths of from 20 to 30 ft., each length being entirely disconnected from the adjoining one except for a cement joint, the idea being that in the event of unequal subsidence taking place by reason of the weight of the embankment on the top, the culvert will not be subjected to the same risk of damage. In the event of subsidence taking place the joints between the various lengths can be made good. Even in good ground—except solid rock—it is well to build the culvert in sections when under high embankments, as there will be subsidence, however slight, due to the weight of the embankment on the strata under the culvert.

This suggests that culverts under high embankments should be built with a vertical camber, as is sometimes done to allow for the varying subsidence which may be expected from the greater weight under the centre of the embankment. If the culvert is constructed on the level and subsidence takes place the hollow in the centre will become silted up and the effective water area will thereby be reduced.

In fixing the line of a culvert under an embankment it is better that it should be constructed by cutting into the sloping ground on one side of the natural run of the stream and thus have a smaller side surface area exposed to the pressure of the made-up embankment, as at Section B, Fig. 15. There would also be less risk of damage to the culvert by reason of any slipping of the material of which the embankment is composed.

The length of culverts under high embankments should be such as will allow of the slopes of the embanking material taking the natural angle of repose. The invert of the water channel between the walls at both ends should be pitched with stone, and at the inlet end the pitching should be laid on a bed of concrete made continuous with the concrete foundation of the inlet walls. A concrete apron should also be formed at the inlet end for the purpose of preventing the invert of the culvert being undermined by flooding, as shown in Fig. 12.

Culverts and waterways should be protected by having a grating placed at the upper end to prevent debris or floating branches of trees choking the culvert and obstructing the flow. These gratings or gates should be placed far enough back from the entrance to the culvert as not to reduce the available area of the waterway or in any way obstruct the free flow of water into the culvert.

Special attention should be given to the design of the ends of the culvert in order to obtain a maximum efficiency (see Fig. 14). The best results are obtained when the inlet has a bell mouth shape and where the approach channel is at the same level as the invert of the culvert. All obstruction by forming corners in the masonry should be avoided. The most objectionable form of inlet would be to have the walls at right angles to the line of the culvert as at (A), Fig. 14, in which case the water entering the culvert forms an eddy, which is a serious obstruction to the free flow. The walls at the outlet end should be carried straight out in the line of the culvert or

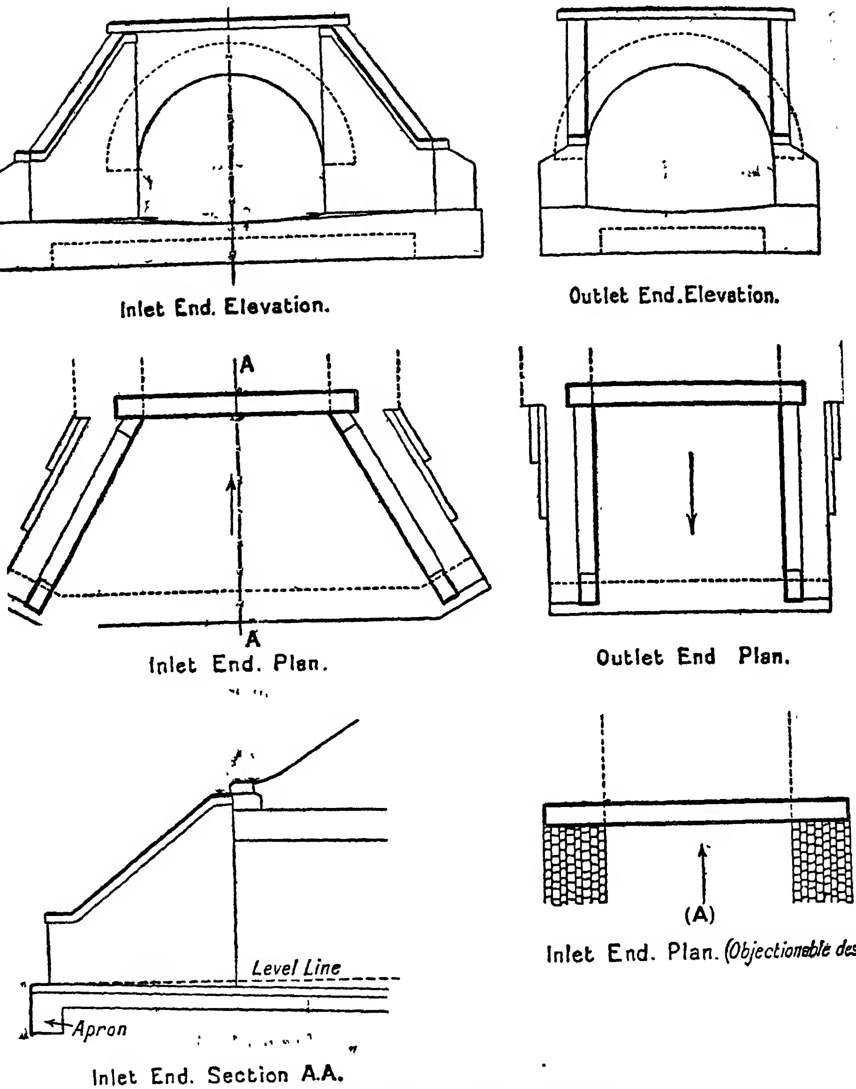



Fig. 14.—Design of ends of culverts.

bell-mouthed the same as the inlet end so as to take the water clear of the culvert.

Culverts should, wherever possible, be straight and have a uniform grade throughout.

Under certain circumstances it may be possible to convey water from two or more water-courses into one culvert and thereby reduce the number and length of culverts under the railway or road (see Fig. 15). Where it is necessary to take the waterway in

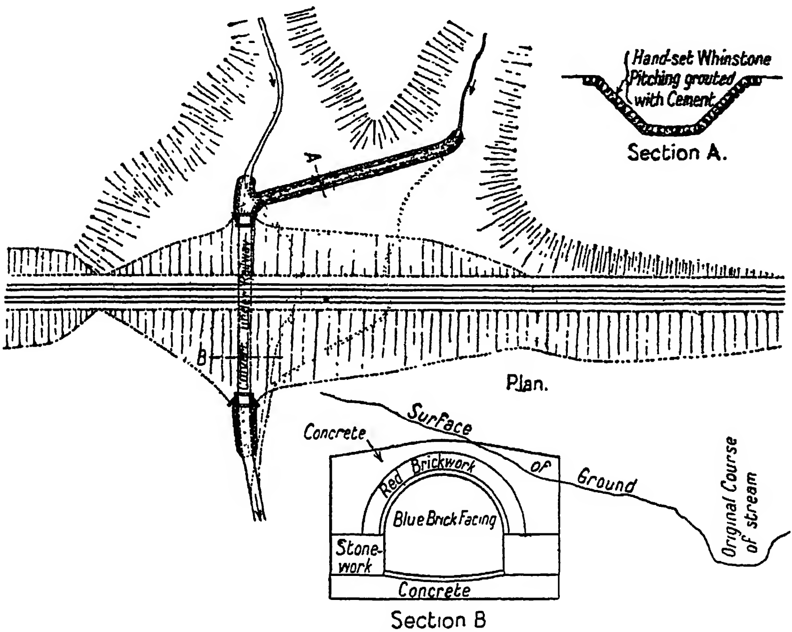



FIG. 15.—Two water-courses conveyed in one culvert under railway.

an open channel alongside a railway embankment the bottom and sloping walls of the channel should be pitched with hand-set stones and grouted with cement to prevent damage to the railway embankment.

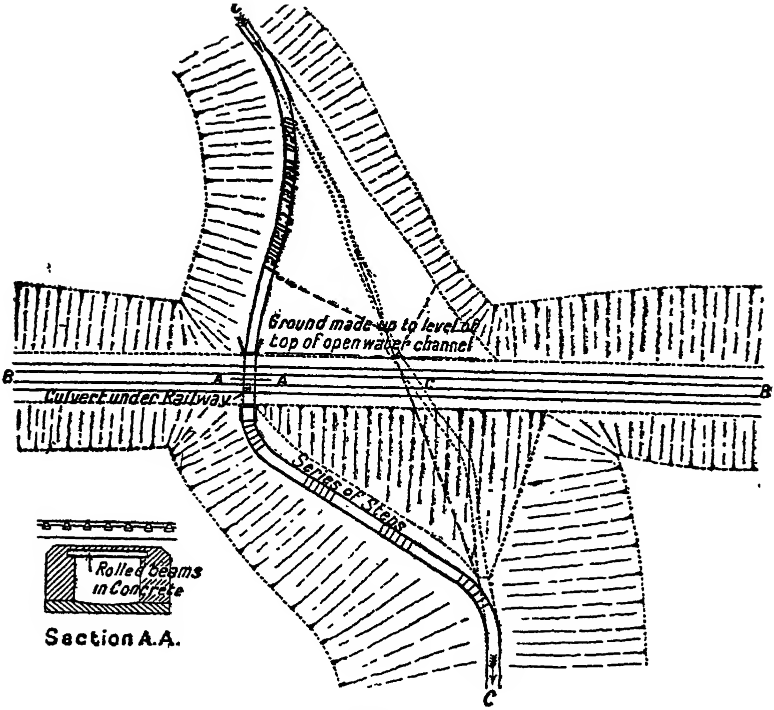
In constructing culverts under embankments it is a common practice to place them in the line of the water-course at the bottom of the valley to be crossed and consequently at the highest and widest part of the embankment. In this situation the culvert may be of considerable length, and the first cost of it,

as well as the subsequent maintenance will form an important item. Where the ground is comparatively flat there may be no alternative, but where it is side-lying and where the stream has a rapid fall it may be possible to divert the water-course on the upper side of the embankment and carry it in open cut or built culvert with very little cover along the contour of the sloping ground and with just sufficient fall to properly carry away the water and thereby cross the railway at a much narrower point (see Fig. 16). By doing so the length of the portion under the railway or road may be very considerably reduced and the part of the conduit in open channel or built culvert would be easily accessible for the purpose of repairs or for the cleaning out of debris which might be washed down. It would, of course, be better that the whole length of the approach conduit should be in open channel, but this may not be possible.

If it can be arranged to have the crossing of the railway or road at the junction of the embankment with the adjoining cutting, the length of the covered channel would be reduced to the width of the formation of the railway or road. The pressure on the arch or upper surface of the culvert would also be reduced to a minimum as the load would only be that due to the weight of the material of which the railway or road surface is constructed, with in addition the live load due to the traffic passing over it.

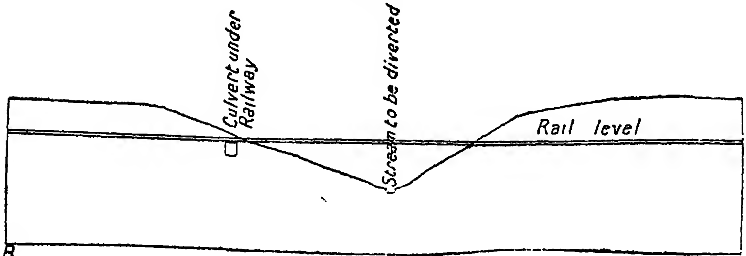
If the stream or water-course is diverted in a manner similar to what has been indicated, the level of the discharge end of the waterway will be considerably higher than the original course of the stream, and it will thus be necessary to construct a series of steps in the part of the channel on the low side of the railway to break the flow of the water, as shown on the diagram, over which steps the water would discharge. If the excavations should be in rock, the discharge would be over a rocky surface and no building would be necessary in forming the water channel.

When diverting a stream from its original course it is necessary to guard against the forming of abrupt corners in the altered channel, which would cause an obstruction to the flow of water, and an endeavour should also be made to have the altered channel constructed so that the flow at the point where it connects with the original course will be as nearly as possible what it was previous to the stream being interfered with, as otherwise damage by flood-

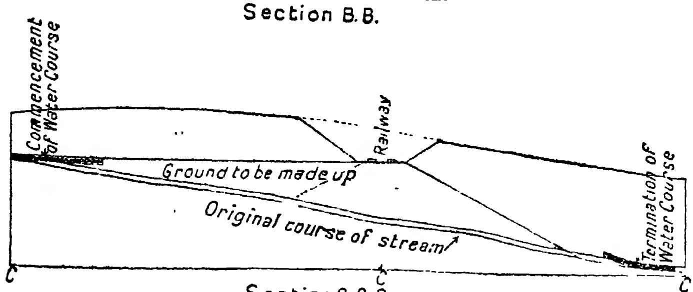



Section A.A.

Plan




Section B.B.




Section C C.

ing may result to the lands either higher up or lower down the stream than the site of the culvert.

In order to prevent the lodgment of water on the upper side of the embankment between the level of the diverted water channel and the original level of the stream where it passes under the bank, the ground should be made up to the level of the diverted water channel if this can conveniently be done, as shown in Fig. 16, the

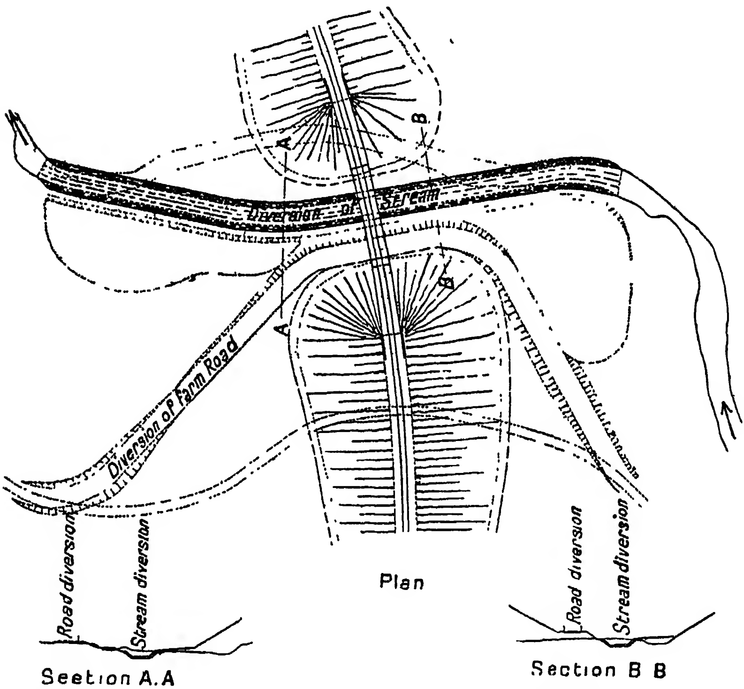



FIG. 17.—Road and stream diversion carried under railway at one place.

embanking material used for the purpose being well consolidated so as to prevent surface water damaging the embankment.

If the filling up of this area is too extensive an operation it will be necessary to lay a pipe or construct a small culvert under the railway embankment to drain this ground.

Every care must be taken in diverting the water-courses to see that there is no drainage left along the original course under the railway embankment, as serious damage may result through the material becoming sodden and slips taking place.

Under certain circumstances it may be possible to take a road and stream under the railway at one place by a bridge as shown in Fig. 17.

Where the water-course is at a higher level than the formation level of the railway and has to be carried across the railway, it will either require to be taken under the railway in a syphon pipe or over it by means of a pipe or box conduit. A syphon would be adopted where there was not sufficient headway for railway traffic to allow of the conduit being taken overhead (see Fig. 18). The pipes forming the syphon would be of iron or steel and the joints made watertight, and the piping would require to be capable of withstanding the pressure of the head of water caused by the difference in level of the top and bottom of the cutting, in addition to any other pressure to which it may be subjected.

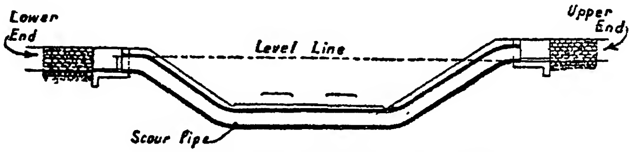



FIG. 18.—Syphon pipe under railway.

When the pipe or conduit is carried over the railway it would be supported on a trestle bridge, or on a road bridge.

If supported on a trestle, as at Fig. 19, there is a danger of drivers or firemen of trains meeting with accident when engaged taking coal from the top of the engine tender, owing to their not observing the pipe as clearly as they would the girder of a bridge. By reason of this, and also on account of the extra cost involved in constructing the piers and framework of a trestle it may be preferable to divert the water-course so as to cross the railway on an overbridge if there should be one near at hand.

In Fig. 20 the pipe is shown carried over the railway on a road bridge, being supported on the outside of the main girders.

If the water-course is larger than can be conveyed in a pipe it can be taken across the railway in an open conduit (see Fig. 21).

The author has knowledge of a case where a stream and farm road were carried over the railway on one bridge (see Fig. 22).

Instead of conveying the water across the railway by any of the methods described it might be taken down the slope of the cutting

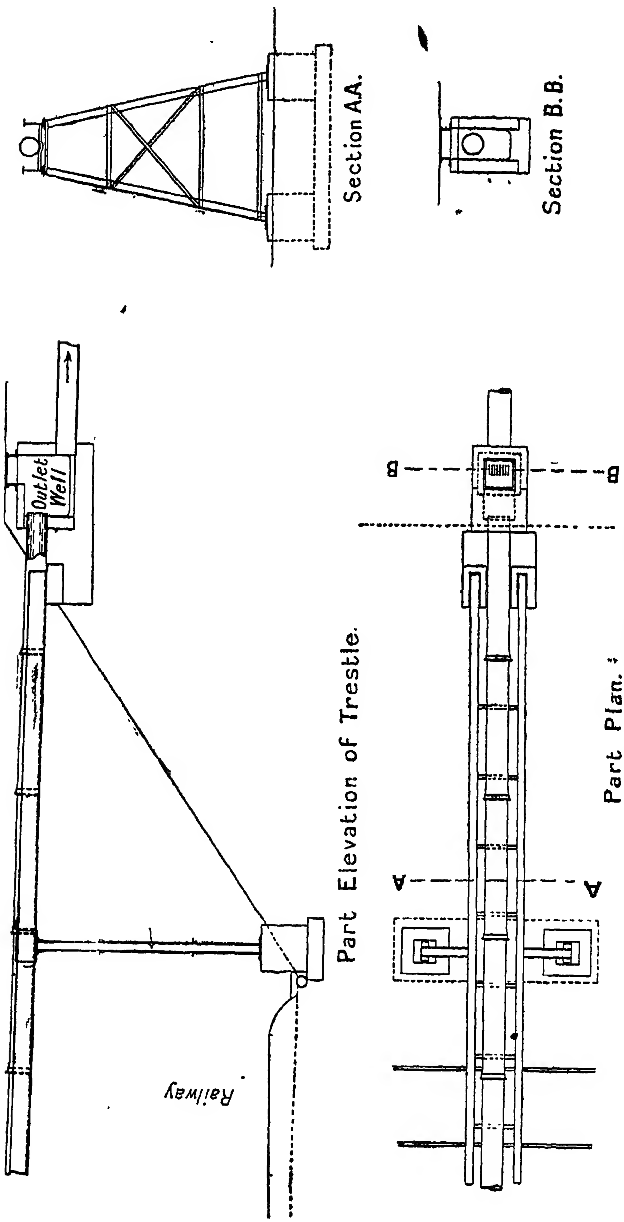



FIG. 19.—Pipe carried over railway on trestle.

either in an open stepped conduit or in a pipe and led alongside the formation of the railway into a watercourse at the end of the cutting. This would, of course, necessitate the making of the formation of the railway wide enough to take the conduit in addition to what is required for the actual construction of the railway, and the additional cost involved might be prohibitive.

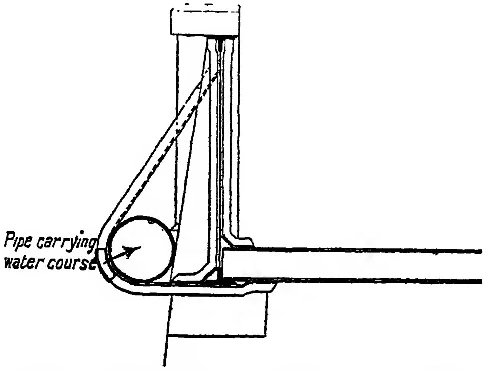



FIG. 20.—Pipe carried over railway on road bridge.

Where a railway is constructed through a town, water, drainage, and gas pipes will have to be dealt with, and provision made for them when designing the bridges carrying streets over the railway or other work.

The question of what drainage works are necessary for the protection of cuttings and embankments of railways is dealt with in Chapter VI.

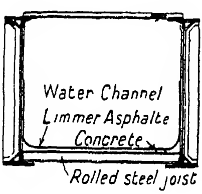



FIG. 21.—Water-course carried over railway in open conduit.

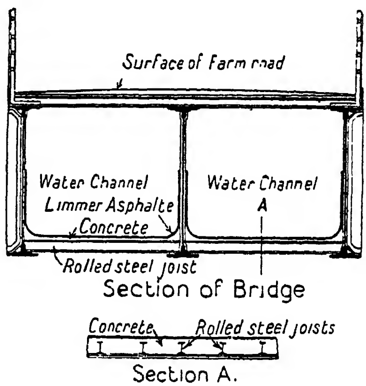



FIG. 22.—Stream and road carried over railway on one bridge.

# CHAPTER IV

## EXECUTION OF EARTHWORK

For the execution of the work there will be a Specification, Schedule of Quantities, and Contract Drawings.

### SPECIFICATION

The requirements of the Contract Specification are referred to in Chapter IX, and it will only be remarked here that so far as the descriptive clauses are concerned they should be as full as possible, both as regards the manner in which the work is to be executed and the quality of the materials used in construction.

### SCHEDULE

The general practice in preparing a Contract Schedule is to detail as fully as possible the various items and quantities of work to be executed in carrying out the work.

Under the heading of " Earthwork " the quantities of materials, whether in road or railway cuttings and embankments, with their situation in relation to the mileage marked on the general plan and section hereinafter referred to, should be separately stated.

Where there is rock in any of the cuttings there should be a separate item.

The quantities of materials in each item of work in bridges, stream diversions, and culverts should also be scheduled in detail.

Sewers and drains which will be distributed generally all over the work should be grouped together under one quantity for each item.

Under the heading of " Sundries " there should be included general work such as office accommodation, the setting out of works, scaffolding, watching, lighting, etc.

The Schedule when read with the Specification should leave no doubt in the mind of the Contractor as to the character and extent of the work to be executed.

In so detailing the Schedule the Engineer furnishes the Contractor with all the information at his disposal, and the Detailed Estimate when priced, on which the Contract Tender will be based, will give, so far as can be seen when the work is let, what the actual cost of the undertaking will be.

### CONTRACT DRAWINGS

The drawings with which a Contractor is furnished to enable him to execute the work usually consist of a general plan, a longitudinal section, a sheet or sheets of cross sections, and detailed cross sections giving width of road-bed or formation, depth of ballast or road forming, the size of side ditches or water channels, drains, etc.

He will also be furnished with typical drawings of culverts and drains for the general drainage of the adjoining lands, and drawings of special culverts or aqueducts for conveying water-courses over or under the railway. The plans should be as complete as possible.

### GENERAL PLAN (see Fig. 23)

The general plan is generally prepared to the scale of the Ordnance Survey of 25·344 ins. to a mile ($\frac{1}{2500}$), or a somewhat similar scale if an Ordnance Survey does not exist, but where there are few divisions of land a small scale plan can with advantage be used. The plan should show the boundaries of adjoining properties, the centre line of railway, the boundary fences on each side, the radii of the curves, and the mileage measured along the centre line relative to a fixed point.

The situation of the principal road and river diversions and how they are to be taken over or under the railway, culverts, and important water-courses crossing the railway, should also be indicated on the plan, and a reference should be made at each bridge or other work to the number of any detailed drawings of the same. Dimensions should be marked on the plan fixing the exact position of the straight portions of the railway relative to existing buildings or fences. No mileage distances

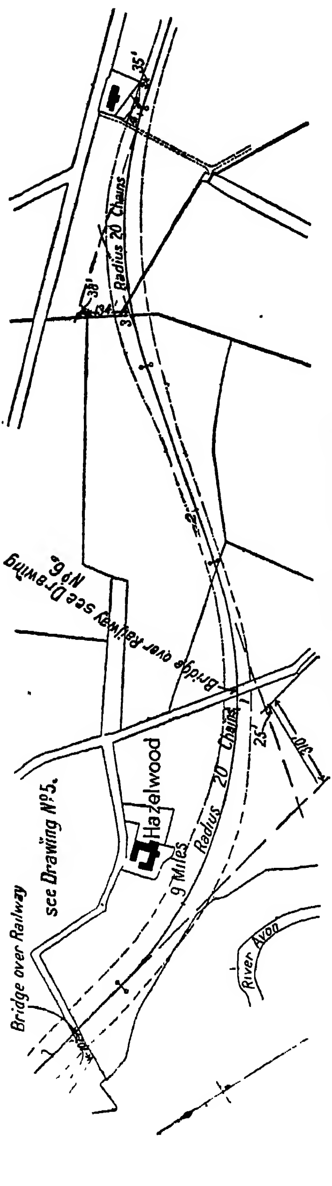



FIG. 23.—Contract—general plan.

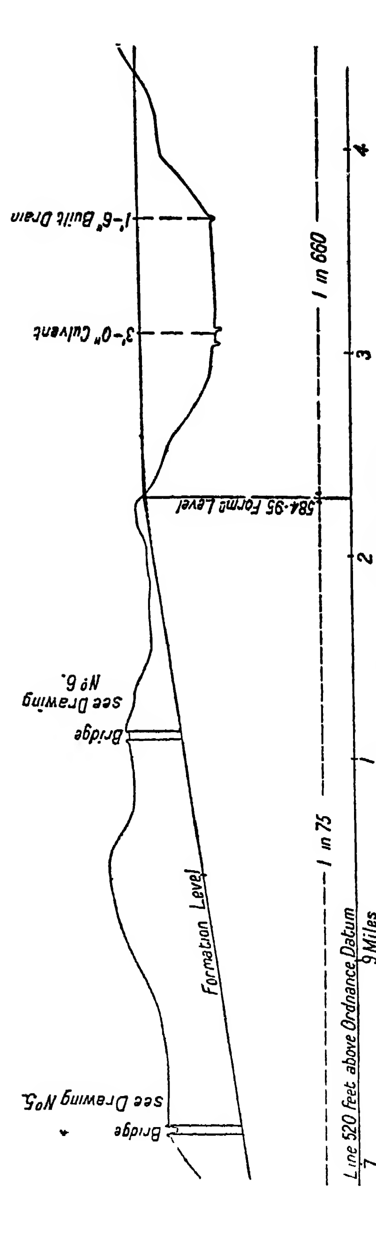



FIG. 24.—Contract—longitudinal section.

should be given to the commencement or termination of the curves as the radii will determine their exact position on the straight portions of the line at each end. The positions of the boundary fences which are ascertained from the cross sections should also be indicated by dimensions from the centre line; and so that the fences will be erected in uniform lines it may be necessary to modify somewhat the widths obtained from the cross sections.

### LONGITUDINAL SECTION (see Fig. 24)

The longitudinal section will show a profile of the natural surface of the ground along the centre line and also the formation level of the railway. It should be plotted to the longitudinal scale of the 25·344 ins. to a mile Ordnance Survey, or to a somewhat similar scale, and to a vertical scale of 1 in. equal to 20 ft. It will be a convenience if the horizontal scale is the same as that of the scale of the general plan. The various gradients will be marked and also the height of formation relative to Ordnance datum at each change of gradient.

For convenience of calculations in the field the gradients should if possible, be stated at a regular figure per chain (66 ft.), per 100 ft. or per 20 metres according to the particular measure of distance in use.

As in the case of the general plan, the mileage of the line should be marked on the section as well as the position of principal bridges or culverts and a reference to more detailed drawings. While the datum line of the section may for convenience be above or below ordnance datum, all levels marked on the section should be the height in relation to ordnance datum.

When fixing the level of formation endeavour should be made to get the quantities of the materials in the cuttings and embankments to balance so far as is consistent with the character of the materials, keeping in view that certain quantities of the material may be suitable for building, road-making, or other uses on the Contract, and also that the excavated material will not occupy the same volume in the embankment as in the cutting, and that an allowance will require to be made for bulking. As regards the allowance made for "bulking" of the excavations, it is usual to assume when preparing the Contract Schedule that the material

in a thoroughly solid embankment will occupy from 3 to 5 per cent more volume than it formerly did in the cutting. The "bulking" of rock taken by itself may be as much as 40 per cent, but as the quantity of rock in railway embankment is generally a small proportion of the whole, the figure of 3 to 5 per cent above stated may be taken as a fair average for all classes of material.

Regard should also be had to the desirability of having the material from the cuttings run down the grade to embankment and with as short a "lead" (haul) to embankment as possible, and it should also be kept in view that the intervention of a rock cutting which will take longer to excavate than a soft cutting, or of a tunnel or viaduct will probably delay the excavations. For the more effective drainage of the permanent way it is also desirable that the line where through cuttings should have a slight fall to one or both ends of the cutting. At a change of gradient a vertical curve should be introduced so as not to have a sudden change when passing from one gradient to another. The maximum or ruling gradient will be influenced by traffic requirements, but it is necessary that the line where through stations, or where sidings join and where it may be necessary to have carriages or wagons standing on the Main Line, shall not be on a steeper gradient than 1 in 260. Where the horizontal measurements are in chains (66 ft.) it is usual to make this gradient 1 ft. in 264 ft. (4 chains).

### CROSS SECTIONS (see Fig. 25)

The cross sections should be plotted to a natural scale of 1 in. equal to 20 ft., so as to correspond with the vertical measurements of the longitudinal section. For the purpose of ascertaining the quantities of material in the cuttings or embankments required for the contract schedule of quantities, and also for determining the position of the boundary fences, cross sections should be taken at every 66 ft., 100 ft. or 20 metres, according to the particular measure of distance in use. Cross sections should also be taken at intermediate points where the ground is irregular in order that the quantity of earthwork may be more correctly ascertained. For the Contract sheet of sections it is sufficient to give sections at every 3 or 5 chains apart, the object being to give the Contractor a general idea of the character of the work. The cross sections

will show the surface of the ground, the slopes of the cuttings or embankments which have been determined upon after consideration of the character of the strata obtained from the bores or trial pits previously put down, and the boundary fences will be placed from 7 to 10 ft. back from the top or bottom of the slope according to whether the line is in cutting or embankment.

Another method is frequently adopted in this country—and usually in America—which would avoid the necessity of taking cross sections at every peg (except at points where the ground is

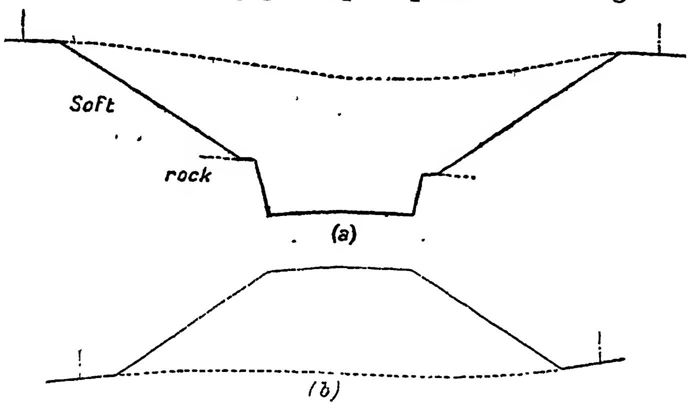



FIG. 25.—Contract—cross sections.

(*a*) In cutting. (*b*) In embankment.

very irregular) and still give the same information, viz. side widths, edges of slopes, areas of cross sections, and cubic quantities of earthwork.

Having completed taking the levels along the centre line and obtained the reduced level of each peg and of the formation level, the heights of embankments and depths of cuttings are known. The Engineer then proceeds to set out and drive the slope stakes opposite each peg, directly on the ground by means of a level, staff, and tape line.

To illustrate the method (see Fig. 26) an embankment 10 ft. deep will be assumed, 30 ft. wide at formation, and having slopes of $1\frac{1}{2}$ to 1. The level is set up conveniently on the higher side of the centre line, the staff is held on the centre peg A and reads, say, 12·50. The staffman then proceeds to some point B, which should

be fully 30 ft. [15+(10×$1\frac{1}{2}$)] from A since ground slopes downward. The horizontal distance A to B is measured and found to be 36 ft., and the staff reading at B is, say, 14·50. Assuming for the moment that B is at the bottom of the slope, the corresponding distance A to B can be calculated. Since A C=10 ft., therefore C D=2·5 ft., and B E=(14·5−2·5)=12 ft., i.e. the height from formation to assumed bottom of slope. The distance from A to B should therefore be (12 ft.×$1\frac{1}{2}$)+15 ft.=33 ft., but as it was actually measured 36 ft., this at once indicates that the staffman must move back nearly 3 ft. towards A. This is done and a second reading of staff at F is taken and same computation made. An expert staffman can frequently obtain the point with sufficient accuracy at the second shot. The bottom of the other slope is similarly obtained, and the

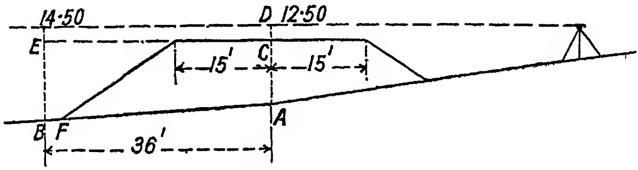



FIG. 26.—Fixing slope stakes.

whole operation for one centre peg can be completed in comparatively few minutes. The same plant for the instrument will usually be sufficient for several pegs on either side of it.

The areas can be readily obtained (see Fig. 27). The hatched area O S T is a constant for each cross section, A C is given, the horizontal distances A F′ and A M′ are measured and O C can be computed. The area F S O T M is therefore equal to $\frac{AF' \times AO}{2} + \frac{AM' \times AO}{2} = \frac{AO}{2}(AF' + AM') = \frac{AO}{2} \times F'M'$, and by deducting from this the hatched portion the area of the cutting is obtained. Since these areas are computed from actual field measurements it eliminates any error in plotting or scaling cross sections.

A special form of field book ruled in columns is generally used for entering up both field work and computed areas and cubical contents of each cutting or embankment.

There are columns for chainage, peg level, and formation level also a column giving the height of formation, above or below

centre peg and slope pegs, and the distances of the latter from the centre peg are also noted.

When a new line of railway is being constructed it may be advantageous to acquire sufficient land to allow for future widening, say, from a single to a double line, or if the line is at first constructed for a double line of railway it may be considered desirable to acquire sufficient land to allow of two additional lines of railway being subsequently provided for future developments. By doing so the land will no doubt be more economically acquired and save the inconvenience of having to obtain further Parliamentary powers or making additional agreements with landowners. Incidentally, it may be remarked that the extra width of land so obtained may be conveniently utilized for a service railway or over-

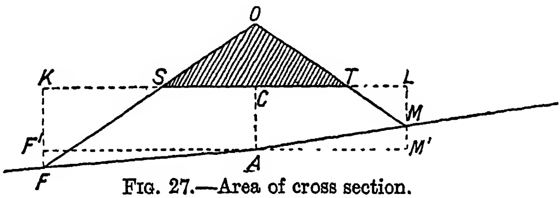


FIG. 27.—Area of cross section.

land route for use during construction of the railway, which otherwise would probably have had to be constructed on land temporarily acquired outside of the boundary fences of the railway.

The contract drawings for culverts and drains will be more or less of a general character, as the particular circumstances in each case can best be determined when the works are in progress.

In works involving the construction of earthwork and masonry it is desirable that operations should commence in the early springtime. It is thus important that the contract specification, schedule, and drawings should be completed some months previously so that the Contractor may have ample time to prepare his tender and also that the Engineer and his clients may be able to give due consideration to the Contract Tenders, and, further, that the Contractor may have full opportunity to mature his schemes for carrying out the work and bringing forward plant and materials. By this means the work would be begun under the most favourable auspices and full advantage would be obtained of the best season of the year.

### SETTING OUT OF LAND AND WORKS

The first operation in the actual construction is the setting out of the land and works. Under the Contract Specification the Contractor is held responsible for the accuracy in position of the works, but in view of the possible legal questions which may subsequently arise as to the boundaries of the promoter's property, it is better that the centre line and the boundary fences be marked off jointly between the promoter's Resident Engineer and the Contractor's Engineer without in any way prejudicing the promoter's position in the matter or relieving the Contractor of his responsibilities.

The centre line of railway should be marked off by having pegs about 1½ in. square by 15 ins. long driven into the ground at distances of 66 ft. apart, or other convenient length. Where the line is across a rock surface chisel markings should be made or iron spikes driven.

The distances along the centre line would be made continuous throughout the whole length and the mileage would be indicated on flat pieces of wood or stakes 3 ins. wide by ¾ of an inch thick, placed immediately behind each peg. The straight portions of the line would be laid down accurately to the dimensions marked on the contract plan and the curves put in to the radii marked on the plan. The pegs on the straight portion would be ranged out by means of a theodolite between the fixed points laid down from the general plan, and the pegs on the curves by deflection angles from the tangent points, transition curves being introduced where required. The intersection points of the curves will in all probability be outwith the boundary fences, and it is therefore most important that the tangent point at each end of the curves should be very carefully marked. This is usually done by having a larger peg for the tangent points and placing a smaller one on either side transversely to the centre line. The tangent points should be transferred to other pegs or fixed points in the line of one of the boundary fences, the distance to the same being entered in a setting-out book specially used for the purpose.

All measurements taken in connection with the fixing of the centre line or transference of the marks should be made with a steel band tape, and for setting out purposes a 5-in. theodolite is very suitable both for accuracy and for convenience in use. For

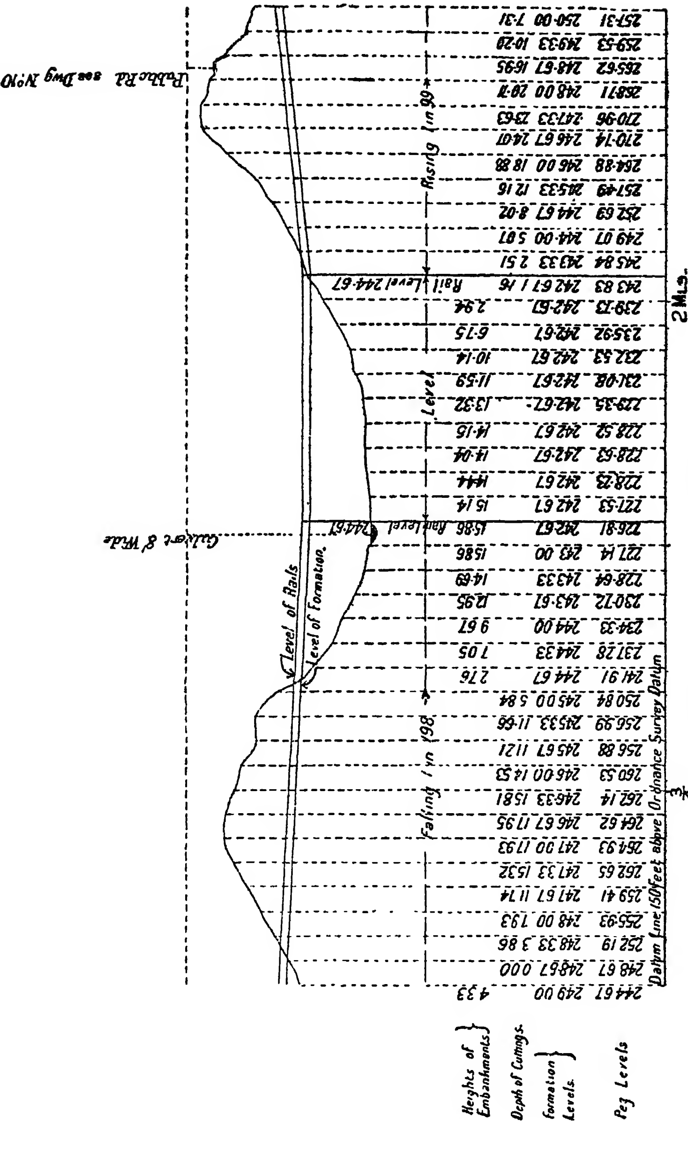



Fig. 28.—Working longitudinal section.

approximate determination of intermediate points on a curve the method of chords and offset measurements may be used, but the exact position of any point either on a curve or straight should only be determined by means of the theodolite.

The levels of the centre line pegs should thereafter be taken, and a working longitudinal section prepared (see Fig. 28) on which will be marked the level of each peg, the calculated formation level of the railway, and the depth of cutting or height of embankment below or above the level peg. It is usual to indicate the peg and formation levels in black figures, the depths of cuttings in red, and the heights of embankments in blue figures on the working section.

When the railway covers a large tract of country a small scale map, preferably 6 ins. to a mile ordnance, with the cutting and banking materials indicated along the centre line in red and blue colours respectively, is very useful for general purposes in locating the site of the works.

When the centre line has been finally laid down on the ground, the boundary fences should be pegged out from measurements previously marked on the general plan. The enclosing of the promoter's property by the erection of walls and fences should be entirely completed before any of the other constructive works are proceeded with, and with a view to protecting the centre line pegs it is desirable that the boundary fences should be erected as soon as possible after the position of them has been marked off.

Previous to constructional operations being proceeded with at any section, each of the centre line pegs for the length to be interfered with should be carefully transferred to fixed points on the boundary fence, so that their original position on the centre line can be obtained at any time as the work progresses. The levels of the pegs should also be transferred. These transfer pegs should for convenience be placed all to the one side of the centre line, and the particulars of situation and level should be noted in the setting-out book.

Considerable inconvenience and expense to the Contractor is incurred when it is necessary to remove only a few inches of material from the slope of a cutting after it has once been dressed off to a regular batter, and it is thus most important that the information furnished by the Contractor's Engineer should be strictly accurate.

### CONSIDERATION OF GENERAL SCHEME OF OPERATIONS

Before proceeding with the actual operations on a contract of any considerable magnitude the Contractor should carefully consider the manner and order in which he proposes to execute the whole work and the various portions of it. He will have looked into this matter in a general way when pricing his Schedule, and when the time limit within which he promised to execute the work was under consideration; but in view of the short time generally allowed to prepare his Tender the *modus operandi* will require to be revised, and the whole question again gone into.

In contracts of other than the smallest dimension, it is unusual to enumerate in detail the minor works to be executed, such as provision of drainage of adjoining lands, the carrying of small water-courses over or under the railway, the diversion of gas and water pipes or electric cables, the construction of roads and bridges necessary for the accommodation of the lands intercepted, etc. While the greater number of these works are necessary for the proper execution of the undertaking, certain of them will require to be determined by agreement with the proprietors of the land passed through, or with public bodies, involving legal formalities. The time so taken up, together with that occupied in the preparation of special drawings, would very seriously delay the commencement of a contract if it were necessary that these should be finally decided upon beforehand. The Contractor must, therefore, keep in view the probability of such works being necessary and his operations should be regulated accordingly.

In terms of his Contract Specification the Contractor may require to take the whole risk of the materials in the excavations or under the sites of the embankments proving different from what he anticipated. While the journal of bores which the Engineer has had prepared previous to the Contract Schedule being made up, and to which the Contractor has access, may correctly represent the character of the materials in the strata at the points where the bores were put down, in view of the importance of the matter, the Contractor may think it desirable to obtain further information by putting down additional bores, or sinking trial pits. If he decides to do so he would put the work in hand immediately after getting

the contract, so that it could be going on simultaneously with the other preparations he is making for having the work commenced.

The result of this check may not materially affect either the total value of the work or the time within which the work can be executed. It may, however, alter the order in which it was originally proposed to execute the work and also the disposition of the necessary plant, and it may be found that the expense of putting down these additional bores was fully justified.

With the information previously obtained when making his Tender, supplemented by the additional particulars he himself obtains, the Contractor will lay out his works in a manner best suited to fulfil the considerations which influenced him in pricing his schedule in respect of the depositing of excavations in the nearest embankment and other points already referred to.

He will first direct his attention to those cuttings which take the longest time to excavate, or from which he expects to obtain building material for use on the work. So that the work may be carried on both expeditiously and economically it may be necessary to proceed with cuttings at more than one point simultaneously.

## SERVICE RAILWAYS

In addition to the ordinary lines of service railway required for the removal of the excavations from the cuttings to the embankments it may be, as already stated, necessary to lay overland routes to take the excavations from the cuttings to the embankments past rock cuttings or the site of viaducts or tunnels under construction. If there is not sufficient space within the boundary fences for the overland route, additional land will have to be temporarily acquired either by the powers of the special Act of Parliament under which the works are being constructed, or by agreement with the land proprietors. Apart from the possible necessity for a service railway or overland route for the removal of excavations, a line of communication is essential for the conveyance of constructional materials required for bridges, culverts, etc., along the line, and for general convenience.

This temporary railway should be laid with a light section of rail, generally flat bottomed, and weighing from 40 to 50 lb. per yard, and would be fixed to light sleepers. The rails should

be placed to the gauge of the railway with which the new line will connect so that building and other materials can be brought forward from the existing lines of railway to where they are required without the necessity of transhipping them. Generally the sleepers of the service railway will be laid on the surface of the ground, with only the inequalities in the surface removed. Where crossing soft or marshy land some additional support may be necessary. The gradient should not, as a rule, exceed 1 in 30, and even with this steep gradient it will probably be necessary at certain places to construct shallow cuttings or embankments. Where any cutting or embankment requires to be done it should, if possible, be on the line of the permanent railway, thereby saving expense.

When ravines or steep ground intervene it will either be necessary to support the line on a temporary trestle with convenient approaches at either end, form a detour to obtain an easier crossing, or entirely break the line of communication.

The service railway will, as a rule, be constructed for a single line, but loop lines or passing places will be required at intervals, of sufficient lengths to allow of trains used in conveying the excavations from the cuttings to the embankments or to spoil passing one another. These passing places should be situated at such points as will cause the least delay to the earthwork operations, and in fixing their position consideration should be given to the convenience for watering locomotives.

### DRAINAGE WORKS

All works connected with the drainage of the land adjoining both the cuttings and embankments, and under the sites of the embankments, should wherever possible be executed before proceeding with the other works, so as to reduce the damage to the earthwork from insufficient drainage. Certain of the drainage outfalls may ultimately be carried alongside the formation of the finished cutting, or taken in conduits over the top of cuttings, and it will thus be necessary to carry them in temporary channels until such time as the permanent work can be executed.

The drainage works required are referred to under the heading of "Culverts and Drainage" in Chapter III, and also in Chapter VI.

## CULVERTS, BRIDGE WALLS, AND RETAINING WALLS

Where culverts are required under embankments, these should be constructed well in advance of the tipping of the materials, so that sufficient time may elapse to allow of the masonry becoming thoroughly hardened, and also that no delay may result in forming the earthwork embankments. The same remarks apply to the construction of abutment walls of bridges under the railway and retaining walls required along the foot of embankments. Where line cuttings are supported by retaining walls, the walls should be built in trench from the level of the top of the wall. The excavations above the level of the top of these walls should be first removed, and, after the walls have been built, the excavations in front should be taken out.

## SLOPES OF CUTTINGS AND EMBANKMENTS

The slopes to which the cuttings and embankments should be formed will depend on the character of the material. As a general rule, cuttings in ordinary soft earth will stand at a slope of $1\frac{1}{2}$ horizontal to 1 vertical.

The slope usually adopted for a solid rock cutting is $\frac{1}{4}$ horizontal to 1 vertical, and where soft material overlies rock there should be a bench 3 ft. in width between the bottom of the slope of the soft material and the top of the rock (see Fig. 29).

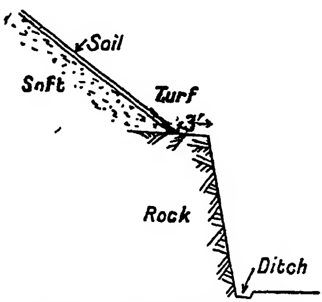



FIG. 29.—Soft cutting overlying rock.

These slopes of soft and rock may have to be modified as a result of the particulars obtained from bores, the amount of water likely to be met with, or other information in regard to the strata.

In the case of embankments of ordinary soft earth the slope of the upper 25 ft. should be $1\frac{1}{2}$ to 1, between 25 ft. and 40 ft. $1\frac{3}{4}$ to 1, and below 40 ft. 2 to 1. This matter is considered in Chapter VI, page 100.

The exact position of the top of the slopes of cuttings and the bottom of the slopes of embankments should be accurately marked

out from the cross sections, and where there are any inequalities in the surface, additional ground levels should be taken and the exact width from the centre line calculated. When the cuttings and embankments are being formed the slopes should be brought to proper line by means of wooden "batter" rules or "profiles," which may be about 6 or 8 ft. long. In depositing the earthwork in embankments, timber cross-heads should be erected at every 2 or 3 chains, and in fixing the height of them an allowance should be made for the subsidence of the embanked material. This allowance for ordinary material should be about 1 in. to every foot in height, and in making up the embankments the width should be proportionately wider.

### SOIL STRIPPING OF SURFACE

After having marked off the lines of the top of the slope of the cuttings to be excavated, and the lines of the bottom of the embankments—known as "lock splitting" of the surface—and after the centre line and level pegs have been properly transferred, the soil and turf over the area to be operated upon should be laid aside for the subsequent soiling and turfing of the permanent slopes.

It is a common practice to deposit this material immediately outside of the top of cuttings and the bottom of embankments, and between them and the surface catch water ditches where, in the case of embankments, it will act as a barrier, forming a temporary toe, against which the embanking material will abut when being deposited.

### PROCEDURE IN LINE CUTTINGS

The simplest form of a railway cutting is where the material to be excavated consists of dry sand or gravel and where the depth does not exceed 10 ft. In such a case the material would be taken out to the full section in one operation. If the cutting exceeds 10 ft. and is less than 18 or 20 ft., a gullet would first be driven at formation level (see Fig. 30). While the gullet is being excavated in advance, the wings BB on each side, above the level of the top of the wagons, would be removed to the full section behind where the excavations are proceeding in the gullet, and loaded up simultaneously with the material from the face of the

gullet. After the top level has been removed the wings CC of the lower portion would be taken off. In trimming off the slopes batter rules would be used and the surfaces trimmed from the top down. It is usual to cut tracks square to the railway and trimmed to the proper batter, these being at intervals of about 66 ft., and the surface of the slopes is dressed uniformly between these tracks. Where the cuttings are of a less depth than 15 ft. the excavations would be removed by hand labour. If the cutting is over 20 ft. deep and has of necessity to be removed by hand the work would be executed in more than one level.

As regards the means adopted for disposal of the excavations, if the "lead" to embankment or to spoil is less than about 80 yards ordinary barrows or light hand-carts would be used; from

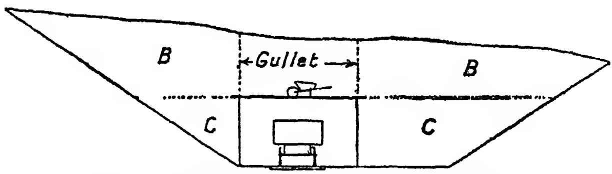



FIG. 30.—Excavating cutting 10 to 20 ft. deep.

60 to 100 yards "dobbin" carts drawn by a horse; and when over that distance and less than about half a mile, wagons of a capacity of 1½ cubic yards, running on light rails placed at 3-ft. gauge and drawn by a horse, would be used. When this distance is exceeded 4½-yard wagons, and worked by a locomotive with from 8-in. to 12-in. diameter cylinder, would be adopted. In the latter case, the gauge of the rails would be the standard railway gauge in use.

The number of wagons taken in a "rake" would depend on the gradient of the service railway, and whether the place of deposit is at a higher or lower level than the cutting, but generally, with 1½-yard wagons and horse power a rake would consist of three wagons, and with 4½-yard wagons and locomotive power it would consist of from seven to ten wagons. The load should, wherever possible, be taken downhill.

In countries where sharp curves and steep gradients are the rule, embankments are generally shallow, and any cuttings that exist are of no great depth. In such cases it may be cheaper to obtain

embanking material from borrow pits situated alongside the line of railway, especially where land is of little or no value.

When the cuttings exceed 15 or 18 ft. deep and consist of "soft" material or loose rock, a steam digger may with advantage be used. If the quantity of material in the cutting is more than from 30,000 to 50,000 cubic yards it will generally be more economical to use a digger. With a clean dry sand or soily material there may not

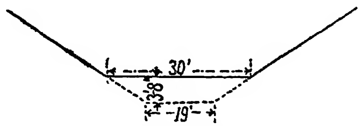



FIG. 31.—Width required by steam digger.

be much saving in cost, but with hard clay, boulder clay, hard-bound gravel, shale or loose rock, which are but slowly removed by pick and shovel, a considerable saving may be effected, and, with all classes of material, the quantity excavated in a given time may be two or three times greater when a steam digger is used than when the material is removed by hand.

It is a common practice when the material to be excavated is very hard to loosen it by blasting in advance of the cutting face.

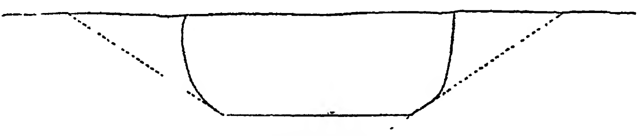


FIG. 32.—Leaving wings on gullet.

The charges would be placed about 20 ft. in advance of the face of the cutting and about the same distance apart and would be sunk to about 12 or 15 ft. below the surface. Care should be taken to see that the charges are at least 3 ft. from the formation slope of the finished cutting, so that the slope may not be damaged. In boulder clay, loose rock, or similar material, the explosive used would be black powder, instead of dynamite or nitro-glycerine, as would be the case if the material to be removed were solid rock, the object being merely to lift the rock off its natural bed or break up the boulder clay so that it may be the more easily removed by the steam digger.

The cutting of a single line of railway with a width of 17 or 19 ft. at formation level is too narrow to allow of a steam digger being used, and it will be necessary to keep the level at which the steam digger is operated about 3 or 4 ft. above formation, as shown in Fig. 31.

When the width is unrestricted, as in the excavations for a depôt or series of sidings, a larger and heavier machine than would work in an ordinary railway cutting may with advantage be used. It is thus that in large canal undertakings considerable quantities of excavations can be removed in a much shorter time and consequently at a less cost than can be done in ordinary railway work.

In the removal of the excavations of a railway cutting long gullets should not be driven in advance of the main excavations

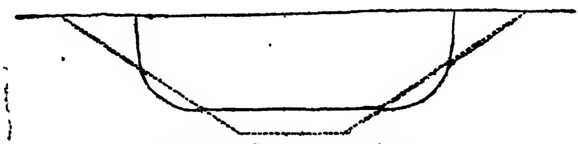


Fig. 33.—Cutting into slope.

(see Fig. 32), as otherwise the weight of the projecting pieces may draw or strain the material outwith the intended slope of the cutting. The sides of the cutting should be battered back as the work proceeds, the slopes being always entirely completed within [illegible] of the working face.

[illegible] objectionable practice is to cut away the toe of the slope when the excavations are being removed by a steam digger (see Fig. 33), and thereafter to throw down the upper portion of the wings to replace the part cut away. As a consequence a slip may result through water finding its way into the back of the material that has been thrown down. If the toe of a slope is so cut away it should be made good by stone filling as referred to in Chapter VI, page 112.

## DISPOSAL OF EXCAVATED MATERIAL

In order to obtain the best results from a cutting it is necessary that the means of disposal be most complete, while at the same time a great deal depends on the management of the operations to ensure that the work is skilfully executed. The usual mode of pro-

cedure in excavating a soft cutting and tipping an embankment where a steam digger is employed is as follows.

Service rails to the standard gauge in use would be laid from the cutting face to the tip ends at the embankment. A light locomotive engine would work at the tip end, while a horse or light locomotive would be employed at the cutting face, and a heavier locomotive than that used at the tip end would run between the cutting and the embankment. If the "lead" to embankment is over two miles, more than one locomotive would be necessary for running the earthwork trains, and passing places would also be required at convenient intervals, probably every two miles.

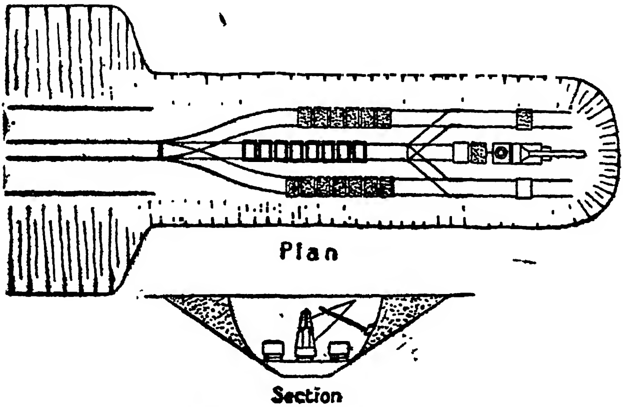



FIG. 34.—Arrangement in cutting—three lines of railway.

The general arrangement at the cutting face where there is sufficient width is shown in Fig. 34.

A short distance back from the face a passing place or loop line is provided for leaving empty wagons and taking away full wagons. At the cutting face the service railway branches into three lines, the steam digger being placed at the end of the centre road. The train of empty wagons, in which there would be eight or ten wagons, would be placed in the centre road behind the digger. An empty wagon would be run by a horse through the "jump" or sharp turn-out and placed at the end of each of the two side roads, so as to be in line with the front of the digger. When each wagon has been filled it is propelled or drawn out into the portion of the side

road behind the "jump" and replaced by another empty wagon. When the whole rake has been filled the next train of empties will be due to arrive and these will be left in the loop while the locomotive engine, which has brought them forward, pulls out the full wagons, and having pushed the train of empties into the centre road behind the digger, the engine takes the full train away to embankment.

With the two side roads there is no delay with the digging operations, as, when a full wagon is being replaced by an empty wagon on one road the digger is filling a wagon on the other road. To be able to get three roads it is necessary that the formation width be not less than 28 or 30 ft., so that in a single line cutting

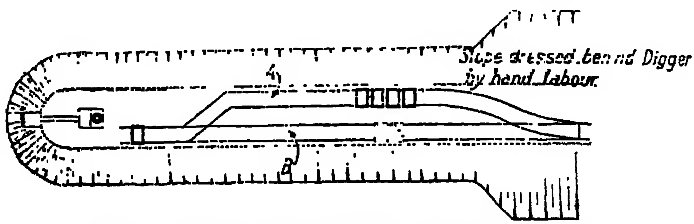



FIG. 35.—Arrangement in cutting—two lines of railway.

operations require to be carried out at a level of about 4 ft. above formation level to get that width.

If the work is conducted at formation level in a single line cutting, which would be about 17 or 19 ft. wide, it is necessary to have the digger placed in advance of the wagon to be filled (see Fig. 35). In this case there would be only two roads. Empty wagons would be placed in the loop, and after each is brought forward and filled it is placed in the straight road from which the whole rake is lifted and taken to embankment.

A steam digger can work well in a cutting from 18 to 22 ft. deep. In deep cuttings the work would be carried on at different levels of 20 to 25 ft. between each. When the depth of a cutting is slightly more than the bucket can reach the material is pushed into the cutting by crowbars or is brought down by the operating of the bucket.

The arrangement at the embankment end is shown at Fig. 36. Full wagons from the cutting are run into the line A. The wagons which have just been emptied are standing on the line B, and after

the engine which has brought forward the full wagons has been uncoupled, it runs the empties back to the cutting. The light engine for tipping is standing in the line B. The first of the full wagons is set in motion by a pinch-bar and run down the line C.

The most favourable conditions for depositing material in embankment are obtained when the lines of railway are falling towards the tip end. In high embankments the gradient can be steepened and the upper or narrow portion subsequently made up.

On the diagram the gradient down to the tip end is shown to be easy so far as the point X, but beyond that point it is much steeper, but not more than, say, 1 in 30.

When the full wagon is within 3 or 4 yards of the tip, the front, which is hinged on the lower edge, is opened by having the fastening

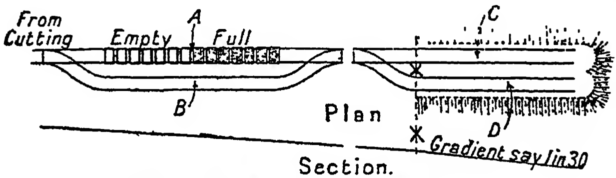



FIG. 36.—Arrangement at embankment end.

at the side thrown up by a man striking it with a shovel. The end of the service road is elevated by having a few sleepers raised above the level of the end rail, and when the front wheels of the wagon strike against this buffer the body of it is thrown up and the muck tipped out.

Meantime the tipping engine has got in behind the empty wagon and immediately thereafter the second full wagon is run through the crossing into the line D and emptied alongside of the first. The engine with the empty wagon from the line C is taken out and run into the line D, and the second empty wagon, having been attached, both empties are taken out and placed behind the full wagon at point A. The whole "rake" having been emptied in this way they are placed in the line B to allow of another rake being run into the line A, following on which the empty wagons are run back to the cutting.

When on account of the shallowness of the embankment or when completing the top portion of a high embankment the material

has to be deposited on a rising gradient, it will be necessary for the shunting engine to propel the full wagons right up to the tip end.

The position and number of the passing places already referred to will be fixed by the time which is occupied in filling the wagons at the cutting or emptying them at the embankment.

### RISKS OF DELAY

When the excavated material is dry no difficulty is experienced in tipping it, but if water is present in the cutting which cannot be kept separate from the excavations, progress is retarded. If the excavated material is gravel the water will probably have

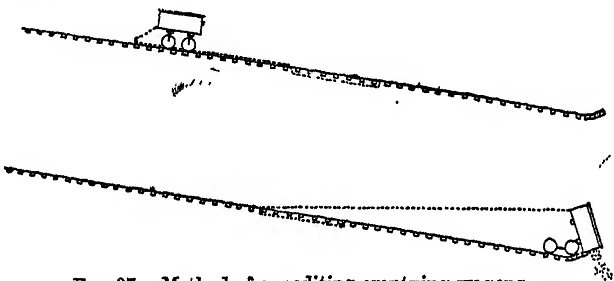


FIG. 37.—Method of expediting emptying wagons.

ned itself off before the embankment is reached; but if it should consist of clay or muddy sand, the material will most likely have been converted into a thick paste, closely adhering to the sides and bottom of the wagon by the time that the muck train has reached the tip end. This adhesion of the material to the wagons may be reduced by spreading a layer of clean gravel or engine ashes in the bottom of the wagons.

For the purpose of expediting the work at the tip end, when bad material is met with the following method has been successfully adopted (see Fig. 37). One end of a chain was fixed between the sleepers on the inclined road and after having been carried underneath several sleepers the other end was attached to the wagon which was being tipped before it had reached the incline. The tip engine, having given the wagon an extra hard push, the wagon was sent down the incline, and on being held up by the tightening

of the chain it was brought to a sudden stop at the tip end and the muck thrown out.

When the material is bad there may be considerable loss of time in removing it from the wagons, and also by reason of derailments, or wagons going over the end of the embankment, in which case the wagons cannot be emptied quick enough to keep the steam navvy constantly employed; but, when conditions are favourable for disposing of the material, the reverse is generally the case, and the supply of excavated material may have to be augmented by having a squad of men working by hand labour filling wagons at some other part of the cutting. In removal of excavations there is always a portion of the slope which cannot be reached by the steam digger, and it is usual to fill so many wagons of each rake in trimming off the slope in the portion of the cutting behind where the digger is working.

In wet weather there is also a great risk of delay by reason of engines and wagons being derailed on the service railway. If the material should be of a clayey description, which with water is converted into a slurry composition, a quantity of it will drop on the way to embankment, and it is thus very important that the line of communication should receive proper attention so as to avoid derailments. The further the embankment or place of deposit is from the cutting the greater is the necessity for keeping the service railway in good condition.

### PROCEDURE ADOPTED IN FORMING EMBANKMENTS

If the embankment is over 20 ft. in height it should be brought up in layers, these being, in the case of high embankments, from 15 to 20 ft. thick. When the width at the tip end is less than 30 ft. two wagon roads would be used in the manner already described; but when the width is greater than 30 ft. additional roads are necessary, an extra road being laid for every additional 15 ft. in width.

When there are three or more lines at the tip end, one of the centre lines would be used for holding the empty wagons after the material had been tipped in the side roads. The centre roads would be carried forward simultaneously with, but a little in the rear of those at the side. In forming an embankment the two

outside roads should be at the extreme width of the completed embankment, as, if it should be necessary to slue them for the purpose of subsequently adding to the width, there is a tendency for the additional material to slip on that which had previously been deposited, the whole object being to get a thoroughly consolidated homogeneous mass.

When forming embankments the centre should be kept slightly above the level of the outer edges, so that water falling on the surface will easily drain off, but care should be taken to ensure that this is not carried to excess as otherwise the material subsequently deposited will have a tendency to slip.

In widening line embankments or in forming an embankment on very side-lying ground it is usual to cut tracks or benches in line of the railway on the sloping ground so as to form grips for the embanked material. These should not be placed closer than 15 ft., and they should have a slight fall longitudinally so as to prevent the lodgment of water.

A deep trench cut along the toe of the new slope and immediately inside of the soil which has been thrown up into a mound to be subsequently used for soiling the slope, will also assist in preventing any movement of the newly deposited material. Where the side-lying ground is pasture land a system of digging or of ploughing the surface to a depth of 9 in. is preferable to forming benches. This matter is further considered in Chapter VI, page 119.

The question of using side tip wagons instead of end tip wagons has frequently been discussed; but the consensus of opinion is that end tip wagons should in general be used for forming railway embankments where they are of a less height than 30 ft., but where the embankments exceed 30 ft. and are of considerable length the use of side tip wagons would expedite operations and might allow of the material from several steam diggers being deposited simultaneously.

When depositing excavations in embankment by means of side tip wagons the whole train of wagons, or as many of them as can be conveniently accommodated, will be run along the service railway to the site of the embankment and emptied simultaneously. By doing so the work will be considerably accelerated, provided wagons can come forward in sufficient numbers from the cuttings.

In a wide embankment formed by side tipping, the work of depositing the material is commenced at the edges of the embankment, and after the service rails are raised to a height of 15 to 20 ft., which would form the level of the first lift, the material will be then deposited on the inner side of the embankment and the service road will be gradually slued towards the centre.

## ALLOWANCE FOR SUBSIDENCE IN FORMING EMBANKMENTS

The allowance for subsidence in forming an embankment will depend on the character of the matérial and the weather conditions existing when the work is being executed, and also to which it will be subsequently subjected. This question is referred to in Chapter VIII, page 140; but it is here remarked that by working traffic over the bank as much as possible while it is being constructed, it is made very compact. Contractors' service railways running on the bank very materially assist in consolidating it; but while the temporary railways are in use it is necessary that the surface be kept as free as possible from hollows so as to prevent water collecting which may sink into the bank, and thereby cause damage. The longer time that can be spared before the permanent railway is laid the better it will be for the embankment.

Before the permanent ballast is put down the surface should be brought to proper line and level. If the top is low it should be raised to the proper height with selected material—preferably good hard clay—which will form a firm seat for the ballast, and if the surface is high it would require to be reduced. It is well, however, to keep the bank a little high to allow for ultimate subsidence.

Considerable difficulty is experienced in countries where heavy rain-storms occur through banks subsiding after the traffic has been brought on to them. If the banks are made from borrow pits they should be formed as early as possible so as to give them an opportunity of settling during the rainy season. In the event of the railway being brought into use before the first heavy settlements have taken place, the railway should only be temporarily ballasted with sand or material from a hard cutting, and subsequently re-surfaced and fully ballasted after settlement occurs.

### CUTTING IN ROCK

The method adopted for the removal of rock from the excavations will largely depend on the character of the rock, and whether it is proposed to use it for building or other purposes on the contract, or merely to run it to spoil embankment.

In the event of the removal of the rock being the primary consideration the material would be taken out regardless of its value, the object being to remove the maximum quantity at the minimum cost. Blasting, if allowed, would then be carried on continuously, and if there is a greater uniform depth than from 12 to 14 ft. operations would be carried out at more than one level (see Fig. 38).

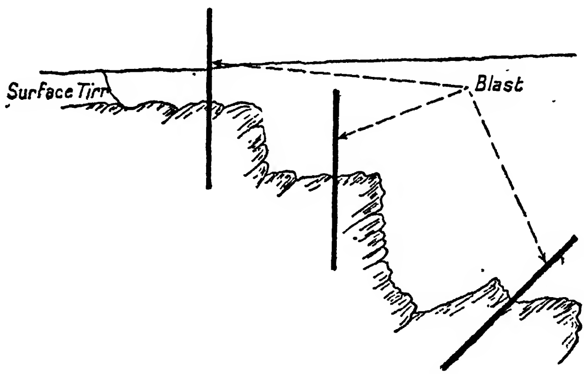



FIG. 38.—Excavating rock.

It will generally be found more convenient to take off one lift continuously for some distance before proceeding with the removal of the rock immediately underneath, but the mode of procedure will largely depend on the means for disposal of the excavated material. The blast holes would be of a depth of about 6 ft. and placed at about 16 ft. apart, but no hole should be closer than 3 ft. to the finished batter of the cutting, so as to ensure immunity from damage to the rock outwith the finished slope. Three men would be engaged at each bore hole, if the drilling is done by hand, while other ten or twelve men would be engaged loading up the excavated material.

The material after being loaded into skips would be lifted and emptied into wagons either by steam cranes placed on the top

of the cutting or by travelling cranes working on the line of railway at formation. As a preventive against stones flying out of the cutting the blast hole should be covered over and weighted down. A good cover consists of pieces of trees 6 in. in diameter and 6 ft. long tied together by chains. If blasting is prohibited by reason of the proximity of property, public highways or adjoining railways, the materials would be taken out by pinch-bars. This matter is further referred to in Chapter V, page 78.

If the removal of the rock from the cutting is not the key to the completion of the work, it would be taken out in large masses in a manner somewhat similar to that usually adopted in quarrying operations. In the case of freestone, limestone, or other stratified deposit the rock would be shifted by splitting it with wedges or by what is known as the "plug and feather" method, and by raising it off its natural bed by means of crowbars. Small charges of gunpowder would be used to shake large posts of rock without shattering it.

Where granite is met with in large quantities blasting will be regularly carried on, and the larger masses which are brought down will be subsequently split up into smaller pieces in a similar manner to the softer stratified rock.

For the removal of the rock so quarried the blocks of stone which are to be used for building or other purposes will be run out into a depôt set apart for the purpose, while the smaller material or debris would be put into tip wagons and run to spoil embankment, or it may be used to advantage for pitching slopes exposed to water, making up roads, or broken up for concrete, or crushed for use as sand, or other purposes.

When rock is met with in station depôts, where there may be platform fronts to be formed in the rock, a track would be cut either by shearing the rock by hand labour or by means of a channelling machine. This would be done previous to the removal of the centre portion, and there would thus be no risk of damage to the sides of the finished cutting.

## EXAMPLES OF RAILWAY CUTTINGS

The following examples from actual practice illustrate the manner usually adopted in the removal of excavations from railway cuttings.

Each of the examples is for a single line of railway where the operations are carried on in a confined width and consequently require more consideration than where there is greater freedom for work.

(1) Fig. 39 is a profile of a railway cutting for a single line of railway, the greatest depth of which was 46 ft. and the quantity of material to be excavated was 80,000 cubic yards. The material consisted of sand and gravel for a depth of 6 ft. under the surface, underlying which there was clay until within 10 ft. of formation, while the bottom 10 ft. consisted of "faikey" fireclay. The line embankment which was situated at the upper end of the grade required about 60,000 cubic yards of material, and the balance of 20,000 cubic yards had to be deposited in a spoil bank at the

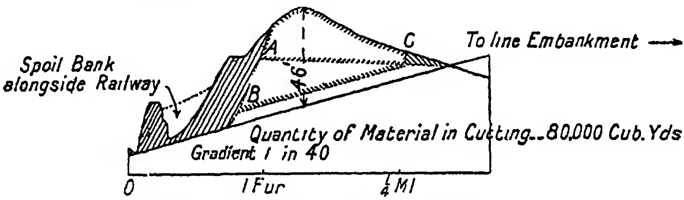



FIG. 39.—Example of railway cutting (1).

lower end of the cutting. The portion of the cutting shown hatched at the lower end was excavated by hand labour, and run to spoil, and a short length at the upper end, sufficient to allow of a steam digger being erected, was also removed by hand.

The digger was wrought through the upper portion of the cutting on a rising gradient taking off the left-hand half of the excavations, following on which it was run back to the point of commencement taking off the right-hand half. It was then run along the service railway to the point A and let down a steep slope to the point B. The triangular portion A, B, C was then taken out, it being necessary to carry on operations at a level of about 5 ft. above formation, in order to get a width of 30 ft. which was necessary for operating the "Ruston" digger which was used. Thereafter the digger was again run through the cutting from the lower end, working this time at formation level. The "faikey" fireclay of the lower 5 ft. was blasted out in front of the digger and lifted by the digger bucket into wagons placed behind the point where the blasting operations were proceeding, the digger in this operation being used merely as

a crane. The whole of the work in each of these operations was carried out on rising gradients, thus allowing of any water that was met with in the working face having a free outfall.

(2) The cutting of which Fig. 40 is a profile had a maximum depth of 37 ft., of which the bottom 11 ft. consisted of solid rock, while the quantity of material to be excavated was 130,000 cubic yards. The material on the top of the solid rock consisted of boulder clay in certain places, while at other places loose rock was met with. Operations were commenced at the lower end of the cutting by hand labour until a depth of face of 8 ft. was obtained, when a digger was erected and taken through the cutting on the top of the solid rock, the excavated material being run to embankment at the lower end of the gradient. Blasting was resorted to in front of the digger for the purpose of loosening the soft rock and boulder clay. After the material on the top of the solid rock had been removed the excavation of the solid rock was proceeded with by hand labour, operations being carried on both at the lower end and at the centre of the cutting, in both cases working up the gradient of the railway. The material from the lower end was run down grade to the embankment, while that from the upper end was taken to embankment up the grade. The excavated rock was lifted into wagons by means of steam cranes placed on the top of the slopes of the cutting. Water was met with in the upper part of the cutting, and this had to be drained off by shearing a track through the rock to the working face at the lower end of the cutting.

(3) In the case of Fig. 41, which was also for a single line of railway, the cutting was 43 ft. deep, while the total quantity of material to be excavated was 245,000 cubic yards. The cutting had a length of 67½ chains (1485 lin. yds.), and consisted of fine sand with a large volume of subsoil water for a length of about 18 chains at the upper end, hard boulder clay, which was perfectly dry, for a length of about 19 chains (418 lin. yds.), hard clay with water coming through open fissures caused by mineral workings, for about 16½ chains (363 lin. yds.), and hard clay without water for the remaining distance of 14 chains (308 lin. yds.).

The excavated material had to be run to embankment from the top end of the cutting. The fine sand at the upper end was excavated by hand labour on a rising gradient, which

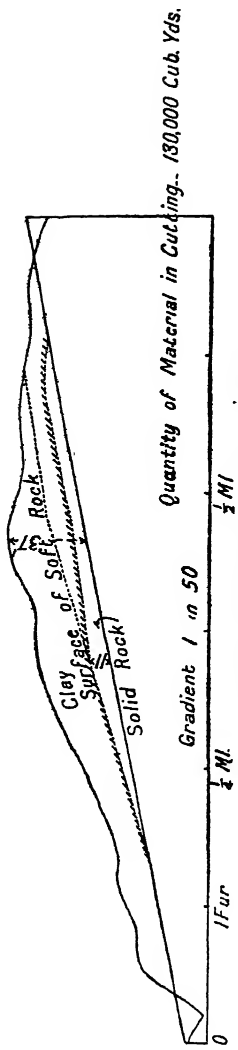



FIG. 40.—Example of railway cutting (2).

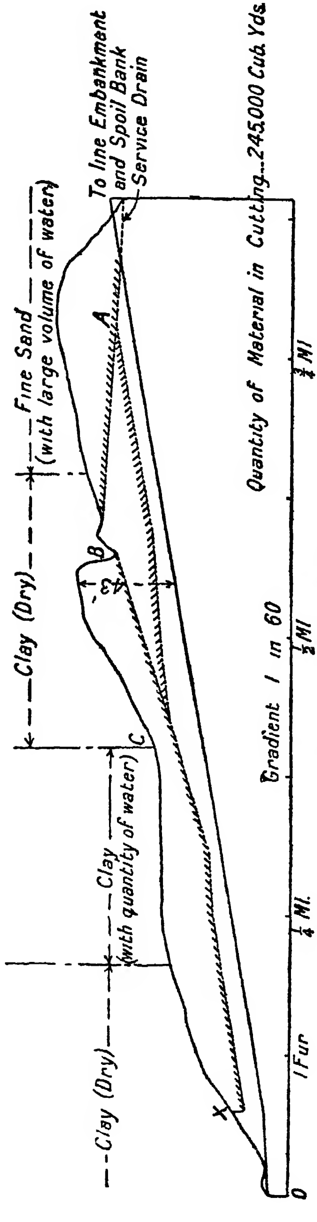



FIG. 41.—Example of railway cutting (3).

had just sufficient fall to allow of the water draining itself off. In the removal of the sand, side and cross ditches were cut so as to have the material when put into wagons as dry as possible. A steam digger was set to work at the point B, and took off one half of the cutting so far as the point C, from which point the digger could reach the full section of the cutting as far as the point X. The excavated material was run back through the sand cutting to the embankment. In excavating the portion of the cutting through the wet clay on a falling gradient it was necessary to have a steam pump, which was erected on a carriage placed immediately behind the digger, for the purpose of raising water from a sump placed at the working face from which the water was pumped into a drain laid at the top of the cutting. The remainder of the cutting was removed by a heavy digger, working at a level of 5 ft. above formation and the lower portion was subsequently removed by means of a lighter digger working at formation. The means adopted to support the slopes of this cutting through the wet sand are referred to in Chapter VI, page 115.

### CROSSING BOG OR MOSS LAND

The surface of a bog consists of peat, coarse grass, heather, etc., and is of a very porous description. If the skin of the bog is unbroken it has a considerable bearing capacity, and if it can be drained the bearing capacity is very largely increased.

If drainage of the surface can be effected no great difficulty will be experienced in taking a railway across it; but if, on the other hand, natural drainage of the surface is impossible the construction of the railway may only be executed with difficulty and at great expense, and the subsequent maintenance will also be a costly item. The ideal railway across a bog is where the railway is either laid on the surface or on a shallow bank and where the bog has a natural drainage. The bog land will be of very little value and ample width should be acquired to make the drainage as perfect as possible.

Fig. 42 shows a section of railway crossing bog land. Ditches 4 ft. wide by 4 ft. deep were cut on either side of the railway 40 ft. distant from the centre line and cross ditches 3 ft. wide and 4 ft. to 3 ft. deep were cut from the longitudinal ditches to within 18 ft. from the centre line and 33 ft. apart. Part of the turf removed

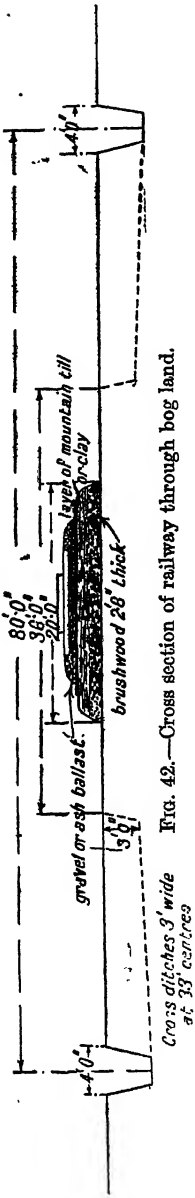



FIG. 42.—Cross section of railway through bog land.

from the ditches was used for levelling up any inequalities in the surface of the ground on which the railway was to be constructed, the object being to strengthen the natural surface of the ground. Brushwood and branches of trees were afterwards laid on the surface for a width of 10 ft. on each side of the centre line and to a depth of 2 ft. 6 in. depending on the springy character of the ground, the lower half being laid with the branches in line of the railway, and the upper half laid crosswise to the line of the railway. The brushwood was covered over with mountain till or clay, which generally underlies the peat and is found along the edges of the bog. On the top of the clay the permanent way of the railway was laid.

The ballasting of the permanent way consisted of ashes or gravel as the slag or broken granite or whinstone generally used cuts through the clay covering the brushwood. With a view to more uniformly distributing the load on to the brushwood covering, the sleepers of the permanent way were placed closer together than usual, leaving only sufficient space for the proper packing up of the sleepers.

If further drainage is thought to be necessary than above referred to, an additional longitudinal ditch could be cut on each side of the railway, in which case the cross ditches connecting the two longitudinal drains may be placed further apart. In the event of any banking material requiring to be deposited on the top of the brushwood care should be taken to ensure that the weight of the banking is placed evenly on each side of the centre line simultaneously, otherwise the unequal loading will tend to break through the surface of the bog.

It is desirable that the ditches for the drainage of moss land should be cut nine or twelve months previous to the laying of the permanent way, and it is also well that the laying of the brushwood should not be commenced until after a spell of dry weather.

On account of the levels of the railway it may be necessary to have part of the line when entering bog land in cutting, and if the bog is very soft it may be necessary to deposit embanking material down to the solid ground underneath. No clayey material should be used for this purpose on account of the water of the bog converting it into slurry. The best material for the purpose consists of the excavations from a rock cutting. If the railway should be in cutting through bog land and the peat is of a somewhat firm description, it may be found sufficient to replace a depth of

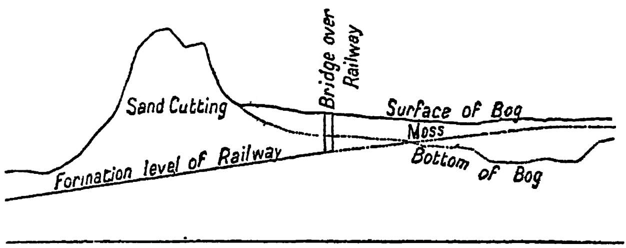



FIG. 43.—Section of railway approaching bog.

2 or 3 ft. of the peat by clay closely compacted, on the top of which brushwood and trees should be placed as in the manner already described.

For the drainage of the railway in a bog cutting deep ditches should be formed along the bottom of the slope on each side.

Fig. 43 shows a section of railway approaching a bog. The bog was contained on all sides and there was no natural drainage. Before entering the bog land a sand cutting 55 ft. deep had to be cut through, and in forming this cutting a drainage outlet for the bog was obtained, otherwise the line across the bog would have been much more difficult to construct.

Where the bog cannot be effectively drained the various works of levelling the inequalities in the surface, the laying of brushwood, and the subsequent claying over of the brushwood should receive special attention. This may not prove effective, and it may be necessary to fill up the bog along the line of railway with

embanking material. The subsequent maintenance of a railway across bog land may be very expensive by reason of breaks taking place in the surface and the necessity for depositing material in order to get a solid foundation.

### WIDENING OF EXISTING RAILWAYS

In executing the widening of an existing railway the first consideration must be the safety and the regular working of the traffic on the railway generally. Trains will no doubt be so frequent that possession of the railway can only be obtained during the night or on Sundays, and any operations during the day will require to be executed entirely clear of the running line.

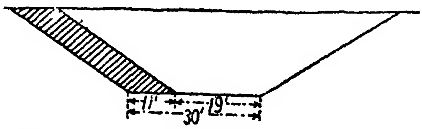



FIG. 44.—Widening of railway—single to double line.

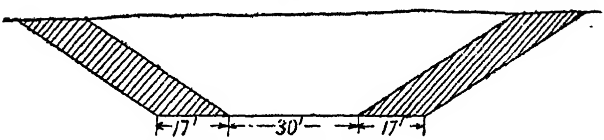



FIG. 45.—Widening of railway—two lines to four lines.

The widening work should be fenced off from the existing railway and any crane or steam digger should be so clamped or controlled that in swinging round it shall have a clear distance of 6 ft. from the nearest rail of the running line.

If the widening is of a single to a double line the total width of the formation of the railway will be increased 11 ft. (see Fig. 44), while if the widening is from double line to four lines the formation width will be increased 17 ft. on each side (see Fig. 45).

It will thus be seen that in the case of the doubling of the single line there will not be clearance for a digger to be employed, and the excavations will, therefore, require to be removed by hand labour.

In the case of widening from two to four lines the operations will not be so restricted and a steam digger can be used if desired.

If the material in the soft cuttings will stand at a steep slope for

a time, it will generally be found convenient to run a gullet through the cuttings at formation level, so that the materials can be taken from both ends of the cutting to the same embankment, and it will also allow of the material in the slopes or stone from rock cuttings being removed simultaneously with the excavations at the ends of the cuttings.

The operations should be proceeded with at as many points as possible along the route of the widening, attention being more particularly paid to the cuttings from which there is the largest quantity of material to be removed, and to the removal of stone in rock cuttings.

It may be necessary to take part of the excavations to an embankment separated from the cutting by a bridge or viaduct which requires to be widened, or to a spoil bank situated away from the widening work, and it will be an advantage to excavate the material at intermediate points, as above referred to, filling the material into wagons placed on the Main Line during the night or on Sundays.

It may also be possible to arrange for trains of excavations to be run over the existing railway from cuttings to embankments situated at a distance or to a spoil bank between traffic during the daytime. Storage sidings for full and empty wagons shall, therefore, require to be provided at the widening work, and there should be no shunting operations on the existing railway.

Any temporary connection with the existing lines should be under the control of the nearest signal box, and when the excavations are being removed from the cuttings into wagons placed on the running lines a flagman should be stationed at each end of the operations to warn the men of the approach of trains.

The traffic on the running lines should be conducted by the Railway Company's engines, and the men and the wagons for the removal of the excavations should also be supplied by the Company.

It will generally be found that the most suitable wagons for the removal of the excavations are those with sides about 3 ft. high and with folding down doors extending the whole length of the wagon.

Care should be taken to see that the wagons are not so fully loaded as to cause the material to spill over on the ballast of the running line.

At the point on the existing line where the material is being

loaded into wagons the ballast should be kept clean by covering with old sleepers or sacks.

In rock cuttings where the material is of commercial value quarrying operations can be proceeded with during the daytime, and the stone can be loaded into wagons placed on the existing line at night or on Sundays.

If the soft excavations are of too hard a description or if rock is to be removed, blasting can be resorted to, but as there may be only one or two occasions during the day when there is a long enough interval between the passing of trains, a number of charges should be fired at one time. The firing of the charges should only be done after permission has been given by the look-out man who has previously arranged the matter with the signalman in the nearest signal box.

## EARTHWORK CONSTRUCTED BY COOLIE OR BLACK LABOUR

In countries where coolie or black labour has to be dealt with, the cost of labour is so low that it would be entirely out of the question to employ costly plant to execute the work.

It is usual to sublet the work in sections or lengths of two or three chains, and both men and women assist at the work. A large number of hands are employed, and the construction of the cuttings and embankments is carried out very speedily. The natives fill their baskets with pick and hoe, and carry them on their heads, except in the case of long loads, when donkeys with baskets or gunney bag panniers may be used.

In some countries light wagons running on a railway of about 2-ft. gauge and pushed by hand are used for conveying the material a distance. Cuttings and banks are formed independent of one another, but instead of depositing the excavations from the cuttings into the embankments they are taken to spoil alongside the railway and the material for the banks is obtained by excavations from borrow pits, except in the case of the part of the cuttings which immediately adjoin the banks, where it is more economical to put the material into the embankments rather than take it to spoil. While this method of procedure entails the handling of a much greater quantity of material than would be the case if the practice of making up the embankment from the line

cutting were followed, it is considered the best arrangement in view of the system of letting out the work which is adopted.

For the making up of shallow banks and the lower portion of high banks, the material from the borrow pits is simply piled on the bank, and in high banks the borrow pits immediately adjoin the end of the bank. The banks should be carried up in layers of two or three feet for the full width and over the whole length, and in depositing the material, the natives should be made to walk over what had previously been deposited so as to have the banks as compact as possible. By the constant walking to and fro a very solid and satisfactory bank is obtained. In executing the work in this manner there is no delay such as is experienced where wagons are used, and where there may be interruptions by reason of them not being timeously forwarded. In excavating rock hand boring tools are generally used, these being considered more economical than machine drills, owing to the supervision which is required for the latter.

### SPECIAL METHODS ADOPTED IN FORMING RAILWAY EMBANKMENTS

In countries where there may be long stretches of level or prairie land, or where the ground may be comparatively uniform in level, and where there may not be sufficient depth or quantity of material to be excavated to warrant the use of heavy plant, scraper machines are largely used.

The earth is loosened by having the surface ploughed over, and after the surface has been broken up, the material is taken to embankment by a drag scraper, where the lead may be from 100 to 200 ft. For longer leads a wheel scraper is used, as it is more economical.

In crossing long stretches of level ground the railway will in all probability be on a low embankment so as to obtain through drainage and immunity from snow-drifts, and if the embanking material is to be obtained from the ground alongside the railway, it can conveniently be deposited by means of a grader working along the foot of the slope and casting up the material as it goes along. The embanking material so deposited will be very loose, and it will be well to have the upper 2 or 3 ft. made up by depositing

the material with drag or wheel scraper for the purpose of consolidating it.

These machines are referred to under Chapter V, dealing with Contractor's plant.

In the construction of railways in countries where there is plenty of timber and where the obtaining of sufficient embanking material may involve considerable delay in bringing the railway into operation, timber trestle structures have been erected to cross deep ravines. These have been placed not with a view to being permanent, but to suit the purpose for the time being, it being intended to subsequently replace them by earthen embankments. The execution of this work can be proceeded with at a time when it is most convenient, and does not necessarily incur any serious interruption of the regular traffic working of the railway.

In delaying the filling of the embankments an opportunity is given to the Engineer to ascertain what size of culverts should be provided at crossing of streams.

### HYDRAULIC METHOD

A large amount of this work of filling in trestles has been done in America, and the method of carrying out the work of placing the material in embankment by hydraulic means would, under certain conditions, appear to have its advantages.

Not infrequently slips of considerable extent have taken place shortly after the opening of a line for traffic, and the material which it is necessary to remove can be conveniently disposed of by filling in trestles at a cost not exceeding that of running it to spoil. If, however, the material requires to be specially excavated and land can be obtained free or at little cost, the hydraulic system commends itself. It has also the advantage that there is no delay by reason of muck wagons blocking the traffic on the railway. For the success of this method it is a necessity that there should be an abundant supply of water with sufficient pressure to operate the plant. Under ordinary circumstances it would not be economical to erect power stations for the purpose of obtaining the necessary pressure.

The operations consist essentially of the washing out of the material from the side cutting or borrow pits by means of a jet of water under high pressure, and the conveying of it to the ground

to be embanked by means of wooden troughs or flumes which are raised or slued as may be necessary as the work proceeds. In the building up of the embankment various means are adopted to dam back the slurry.

On the Northern Pacific Railway a method successfully adopted was to deposit alternate layers of earth and straw. The earth was spaded out from the inside, and on the top of it was laid a bed of straw, this being compacted by another layer of earth. The embankment was carried up in this manner until within a few feet of the surface of the railway, and the upper layer was afterwards formed with material deposited from wagons in the usual way. The deposited material became remarkably solid in a very short time and the embankment was entirely free from subsidence.

### EXAMPLE OF EXCEPTIONALLY HEAVY EARTHWORK

The execution of exceptionally heavy earthwork on a line of railway in New Jersey is worthy of attention.[1]

The line has been formed across country with the object of reducing the distance and also improving the curves and gradients which previously existed on a former line of railway.

By the former route the length between the points of termination was 40 miles, while by the new line the distance was reduced to 28½ miles. On the former line the maximum curve was 6° 54′ (831 ft. radius), and the maximum gradient was 1·14 per cent (1 in 87·7), as against 3° 30′ (1637 ft. radius), and 0·55 per cent (1 in 181·8) respectively by the new line.

The excavations and embankments are of exceptional magnitude, there being 7,315,000 cubic yards of excavations and 14,621,000 cubic yards of embankment. There is thus an excess of 7,306,000 cubic yards of embankment which had to be obtained from side cutting or by the bulking of the rock when put into embankment.

One of the embankments extended in length to three miles and had a height of from 75 ft. to 110 ft., the quantity of material required to fill it being 6,625,000 cubic yards.

The high banks were brought up in lifts of 30 ft., timber trestle bridges being largely used for the purpose of tipping the material.

[1] *Engineering Record*, 17th April, 1909.

In forming some of the large embankments cable-ways were adopted. In one instance a cable-way had two spans of 1000 ft. and 1200 ft., with three wooden towers 60 ft., 150 ft., and 135 ft. high respectively. The working of the cable-way is described as follows :—

"It is essentially a suspension bridge, carrying a cage or platform on which a 3-ft. track is laid. The cage is so made that it can be moved forward along the main cable as fast as the embankment is built. The cars are pushed to the very edge of the fill and dumped and then pushed out on the cage, which is of sufficient length to hold eight cars, or a gross load of 48,000 lb. As the fill progresses the suspended track is shifted along the cables by placing clamps 12 ft. apart in advance of the previous ones and hanging from them a suspender rope with an adjustable tackle, to which a needle beam is fastened to carry the new stringers and the additional track. On account of the sag in the cables the lengths of these suspenders and other tackle are made adjustable."

It is claimed by this method that there is greater ease of working when the excavation consists of rock or large boulders which might seriously damage a timber structure.

The borrow pits from which the extra embanking was obtained were situated above the level of the banks, and in some instances the loaded tip wagons were allowed to gravitate to the bank, being kept in check by having one end of a cable, which passed round a drum, attached to them, the other end being connected to the railway wagons which were drawn back to the pit for refilling.

## CHAPTER V

# PLANT USED IN EXECUTING EARTHWORK

An axiom in manufacture by machine tools, which is equally applicable in the execution of earthwork, whether by hand or machine labour, is that the system or machine which accomplishes a given result quickest, best, and at the same time at the least cost, is the one to be selected.

### REMOVAL OF EXCAVATIONS BY HAND LABOUR

*Soft excavations.*—The shovel is the tool in general use for the removal of soft excavations by hand labour. The iron blade of the shovel is of a hollow or scoop shape, and is usually sharp pointed. Where the material to be removed is of a wet or muddy description, the shovel would be broad pointed, and the sides turned up so as to better contain the material.

Except in the case of loose earth, or when the material is easily removed, a pick would be used in conjunction with the shovel to loosen it.

Where the material is of a tenacious, clayey description and free from stones, it may be dug out by a sharp-pointed shovel with a thick upper rim, similar to what is on an ordinary broad-pointed spade, and would be used in a similar manner.

It is very desirable that the shovel, spade, or pick should be of as light a character as possible, consistent with the rough usage to which it is subjected, in order that the energy expended in handling the tool may be reduced to a minimum.

*Rock excavations.*—In excavating shaly or loose rock, or rock which can be removed from its natural bed without blasting, a pick is used. The point of the pick is driven into the joints or clefts of the rock, and, by using the curved back of the pick as a fulcrum and pulling back the end of the shaft, a considerable pressure can be brought to bear on the point in removing the rock.

A pick for removing rock has generally a broad or chisel-shaped point at one end and rounded point at the other end. By having a broad point there is more of a knife edge, while at the same time equal strength, and this allows of the point of the pick being inserted into a closer joint than a blunt rounded point would enter. The pick in use for the removal of soft material is rounded at both ends.

A crowbar chisel-pointed at one end and round-pointed at the other end, similarly to the pick, is used where greater pressure is required than can be obtained with a pick. For the purpose of getting a leverage a piece of wood, stone, or other hard material at hand is placed under the bar so as to act as a fulcrum when prising up the rock, and by inserting wedges in the open joint the bar can be released or tilted up to allow of the fulcrum being shifted closer to the joint, thereby getting into a better position to further raise the rock from its bed. Where a large block of rock is being lifted from its bed two or more crowbars may be used simultaneously.

Where the rock is of a close or solid description a groove is formed in it with a pick, along the line on which it is to be split, and iron wedges are driven at intervals by blows from a sledge hammer. The wedges are placed at about a foot apart and the blows applied on every alternate wedge when passing over them in one direction, driving the intermediate wedges when coming back over them. The rock is, of course, more easily split along its natural bed than at right angles to the bed.

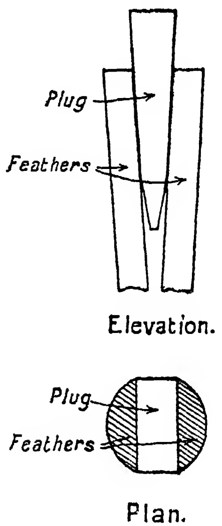


FIG. 46.—Excavating rock by "plug and feather."

If the pieces of rock so loosened from their beds are too large to lift by hand or by the crane power which is available, they are broken by means of a sledge hammer or split by wedges, or by "plug and feather." The latter method is, as a rule, only adopted when the rock is to be used for building purposes, in which case care is necessary to ensure that the blocks are regular in shape.

The "plug and feather" (see Fig. 46) consists of a wedge-shaped piece of steel, or plug, which is driven between two segmental-shaped pieces of wrought iron or feathers. The holes in which the feathers are placed are drilled by a chisel or small hand drill. The plugs are driven in between the feathers alternately as in the case of wedges until the rock splits along the line of the holes.

### REMOVAL OF EXCAVATIONS BY MECHANICAL MEANS

*Soft excavations.*—The expediency of removing earthwork by mechanical means has already been referred to. Various machines are in use for the removal of soft excavation, but for ordinary railway work the principal one is the steam digger or shovel.

The primary requirement in a steam shovel is to have a machine that will withstand a large amount of rough usage, and consequently the working parts must be made of the toughest material. In this connection cast steel is largely used. The design of the machine must also allow of a certain "play" or freedom of action which will take up the jolting or hammering without the parts which must of necessity be close fitting being unnecessarily strained.

The various movements of a steam digger are very similar to the movements of a man when excavating earth by hand labour. The hand shovel is first lowered, then pressed into the ground, and when filled it is raised, swung round and emptied into a barrow or wagon.

In the case of the steam digger the bucket is first lowered into the bottom of the cutting by releasing the lifting rope. It is then pulled up, being at the same time pressed into the cutting, and when filled, it is swung round and the excavations emptied into a wagon.

### RUSTON STEAM CRANE NAVVY

The Ruston steam crane navvy is the digger in general use in Great Britain, and is typical of the best class of this machine.

In the earlier type of Ruston digger, the boiler and lifting gear were fixed to the carriage in a similar manner to what is done in the Ruston steam shovel, hereafter referred to, and could thus only revolve through about 180 degrees; but in the Ruston steam

navvy or digger now in use the machine revolves through a complete circle, thereby allowing of wagons being loaded immediately in the rear of the machine.

There are several sizes of Ruston steam navvies, but the machine most suitable for general railway excavation work is what is known as the No. 12 machine (see Fig. 47).

The nett weight of this machine is 41 tons, and it will work in a cutting 27 ft. deep without breaking down the top by hand. On account of the long reach of the jib, the digger is able from one position to excavate to a width of 42 ft. at the bottom of the cut to 63 ft. at the top. This range of working allows of the excavated material being loaded into wagons with less shunting and also of the bucket being brought more directly over the wagons, thereby reducing the labour in cleaning up material that may have dropped over the sides of the wagons. The door of the bucket when open will clear a height of 19 ft. above the level at which the digger is placed and where the cutting does not exceed 10 ft. deep, or where the cutting is in side-lying ground with the low side not more than 10 ft. deep, the excavations can be loaded into wagons placed on a line of rails outwith the cutting, which may be a considerable advantage in the removal of the excavations to embankment or to spoil.

It is not proposed to enter into the mechanical details of construction of the machine, but the following details should be noted.

The boiler is of the vertical cross tube type, and the water previous to entering it is heated in a water heater by exhaust steam, this resulting in a considerable saving of fuel.

The jib is constructed of steel plates and heavy angles, and the bucket arm which consists of two oak beams, one on each side of the jib, is heavily reinforced by mild steel plates so as to withstand the heavy stresses to which it is subjected.

The stroke of the bucket arm is controlled by toothed gear fixed to the jib, which engages with long steel racks fixed to the underside of the bucket arm, the toothed gear being operated by engines mounted on the jib.

The bucket is heavily constructed of steel plates and angles and fitted with a steel casting to receive the bucket arm. The teeth, of which there are four, are carried about the full depth of the bucket and consist of mild steel shanks with renewable manganese

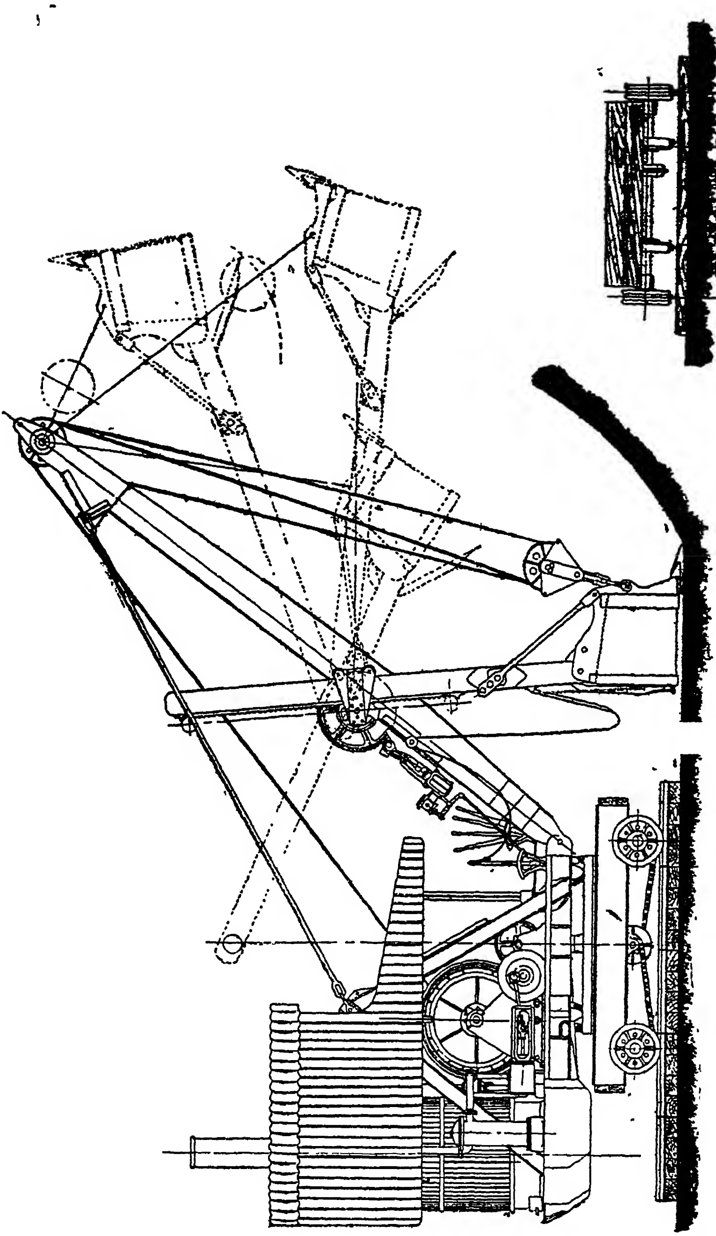


FIG. —Ruston steam crane navvy.

steel points fitted on a renewable lip plate. The teeth are fitted to the bucket plates with counter-sunk bolts, which allow of them being quickly renewed.

The hoisting rope is double and the drum, which is of a large diameter, has right- and left-hand grooves on it, so as to increase the life of the rope and also equalize the pressure upon the drum bearings and side frames.

The carriage of the digger is supported on two axles with wheels to suit both the ordinary gauge of 4 ft. 8½ in. and a gauge of 9 ft. 6 in., the narrow gauge being provided for the purpose of travelling the digger from one section of the railway to another, while the broad gauge wheels, which are provided with double flanges, are used when the digger is in operation, thereby giving the machine a broader working base.

In carrying out the work, when the bucket is lowered to the bottom of the cut it is allowed to swing a little past the vertical, and in doing so the catch of the door drops automatically into its place. The bucket is then pulled up the face of the cutting, being kept hard pressed into the cutting by the racking engine. After it has reached the top of the cut, or if it is filled before it reaches that height, it is pulled a little back from the cutting face and slued round until it is over the muck wagons, and, when in proper position, the door of the bucket is released by the man at the jib pulling a cord which is attached to a link connected with the catch of the door.

The bucket generally used with No. 12 machine has a capacity of 2 cubic yards, which represents about 1¾ cubic yards of solid excavation.

For heavy railway excavation work with large quantities of material to remove, the Ruston No. 20 machine is well adapted.

The nett weight of this machine is 55 tons, and it will work in a cutting 29 ft. deep without breaking down the top by hand. The digger, from one position, will excavate to a width of 44 ft. at the bottom of the cut to 72 ft. at the top. The bucket generally used with this machine has a capacity of 2¾ cubic yards, representing about 2½ cubic yards of solid excavation.

To allow sufficient space to operate these machines it is necessary that the cutting should be not less than 30 ft. wide at the bottom, so that in a single line cutting it is necessary that the level at which

the digger is operated should be about 3 or 4 ft. above formation level of the railway.

As already stated, the output from a cutting which is being excavated by means of a steam digger is largely controlled by the facilities which exist for having the excavations removed, but with a constant and uninterrupted supply of wagons for taking away the material and with operations carried out under favourable conditions the No. 12 Ruston navvy has excavated 350 cubic yards of boulder clay and 800 to 1000 cubic yards of sand in a working day of ten hours; while the No. 20 machine has excavated 550

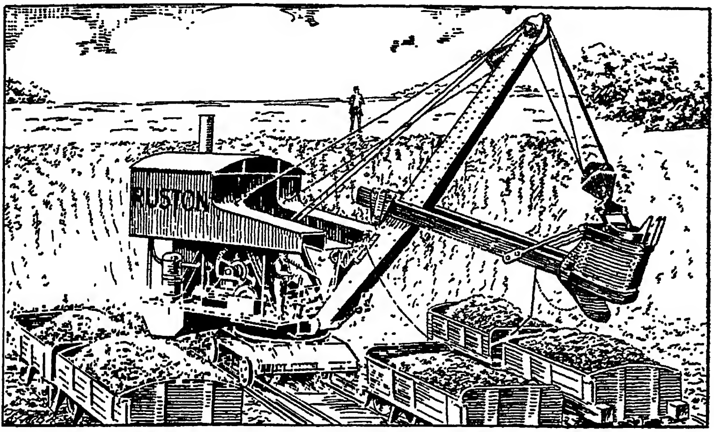



FIG. 48.—Ruston steam crane navvy.

cubic yards in well blasted rock, and 1200 to 1400 cubic yards in a chalk cutting during the same time. These figures would, of course, require to be reduced to make allowance for bad weather or other delays.

The relative output of the two sizes of machine referred to may be said to be proportionate to the pressure of the teeth of the bucket on the cutting face, which in the case of the No. 12 machine is 12 tons, and in the case of the No. 20 machine 20 tons, and the capacity of the lifting bucket is arranged accordingly.

By removing the bucket and bucket arm, the navvy can be used as an ordinary steam crane, the lifting power of the cranes being 12 tons and 20 tons respectively.

The illustration (Fig. 48) shows the usefulness of the long racking gear. It will be observed that five wagons were loaded from one position of the digger.

## WILSON STEAM CRANE NAVVY

The Wilson steam crane navvy, illustrated at Fig. 49, is also largely used in Great Britain for the removal of earthwork.

So far as actual working results are concerned, the 12-ton Wilson

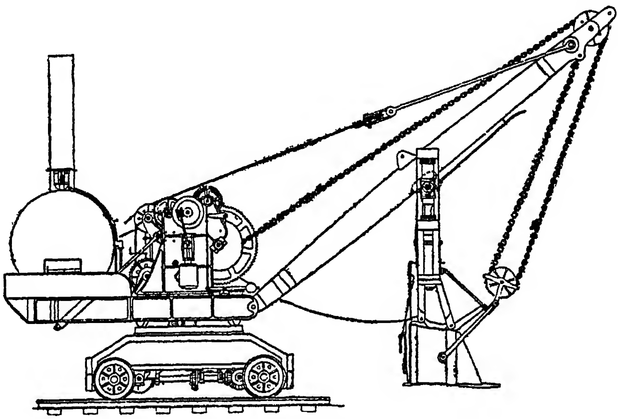


FIG. 49.—Wilson steam crane navvy.

navvy is very similar to the No. 12 Ruston navvy already referred to, and is an equally serviceable machine.

Instead of the long bucket arm in the Ruston digger the Wilson digger has a "luffing" jib, thereby lengthening the reach of the bucket.

The special feature of this digger is the steam racking cylinder which operates the bucket arm. The cylinder is bolted to the arm and the arm is pivoted to the underside of the jib and radiates therefrom. The bucket is fed up to its work by means of the racking cylinder, and can be moved in or out a distance of 2 ft. as desired.

The jib can be adjusted from a minimum radius of 16 ft. to a maximum radius of 25 ft. The machine weighs in working order 43 tons.

Some of the machines of this type are provided with a bent jib (see Fig. 50), the advantage of which is that it allows wagons to be brought closer to the machine, thereby reducing the labour in bringing forward the wagons.

This digger can conveniently work in a width of 25 ft. at formation level, and will reach to a width of 50 ft.

The bucket used for average material has a capacity of $2\frac{1}{4}$ cubic yards, and can excavate a cutting 18 ft. deep without breaking down the top by hand.

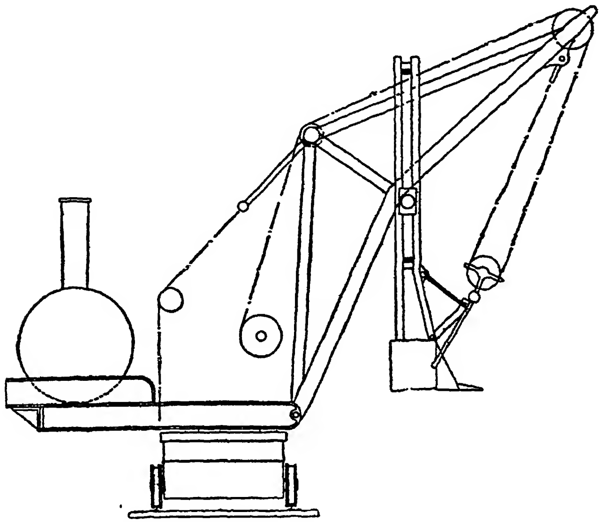


FIG. 50.—Wilson steam crane navvy (with bent jib).

When used as a crane this steam navvy will lift a load of 12 tons at a radius of 16 ft.

### RUSTON STEAM SHOVEL

The Ruston steam shovel, illustrated at Fig. 51, is specially made for dealing with heavy earthwork in large quantities, and where the operations are not confined to the limits of an ordinary railway cutting.

The nett weight of this machine is 78 tons, and it will excavate a cutting 27 ft. deep with a maximum cutting radius of 32 ft.

The bucket has a capacity of $3\frac{1}{4}$ cubic yards.

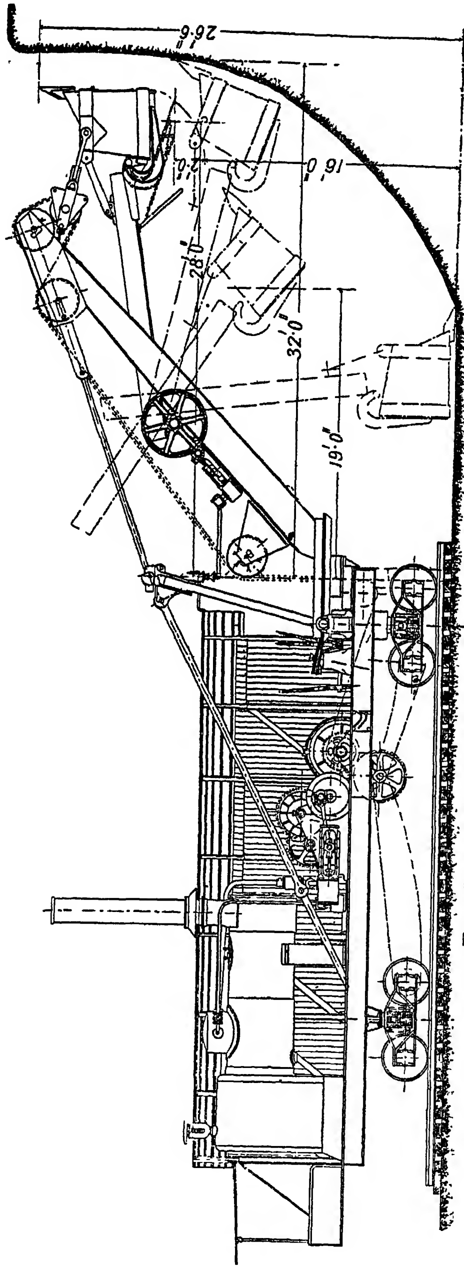



FIG. 51.—Ruston steam shovel. (*The Engineer*, 9th April, 1915).

The larger output consequent on the more powerful description of the machine commend it for specially heavy work.

### LUBECKER LAND DREDGER

This digger machine has been extensively used in connection with canal excavations and also to a limited extent in railway work where a large quantity of soft material has to be removed.

The machine is built on the same principle as a marine dredger (see Fig. 52), the excavations being removed by a series of buckets attached to two endless chains. The machine is of two types, to cut out the excavations either above or below the rail level on which it travels.

It works on rails running parallel to the direction of the cutting, advancing automatically on the rails as the work progresses, i.e. as the chain of buckets projecting at the side excavates the soil and throws it into trucks for transportation. The trucks stand behind the excavator and at the same level on which the machine is placed.

In order that the chain of buckets may be kept constantly in use it is necessary that the rails on which the machine travels should be shifted forward from behind the machine, this being done after the machine has made one or several cuttings, and, so as not to disturb the operations, there should be a length of railway equal to from three to five times that of the train of wagons which is being filled.

To prevent the sand or earth from falling between the trucks the machine is provided with movable chutes, which may be turned round so as to direct the material from one truck into the next and prevent it falling on to the track.

### ROCK EXCAVATIONS

Where rock is removed by blasting, the drill holes into which the explosive agent is inserted may either be driven by hand or by machine drills. Speaking generally, the harder the material and the more difficult to drill by hand, the greater is the advantage of machine drilling.

In open cuttings of railways there is generally a much larger proportion of soft material than rock, for the reason already stated

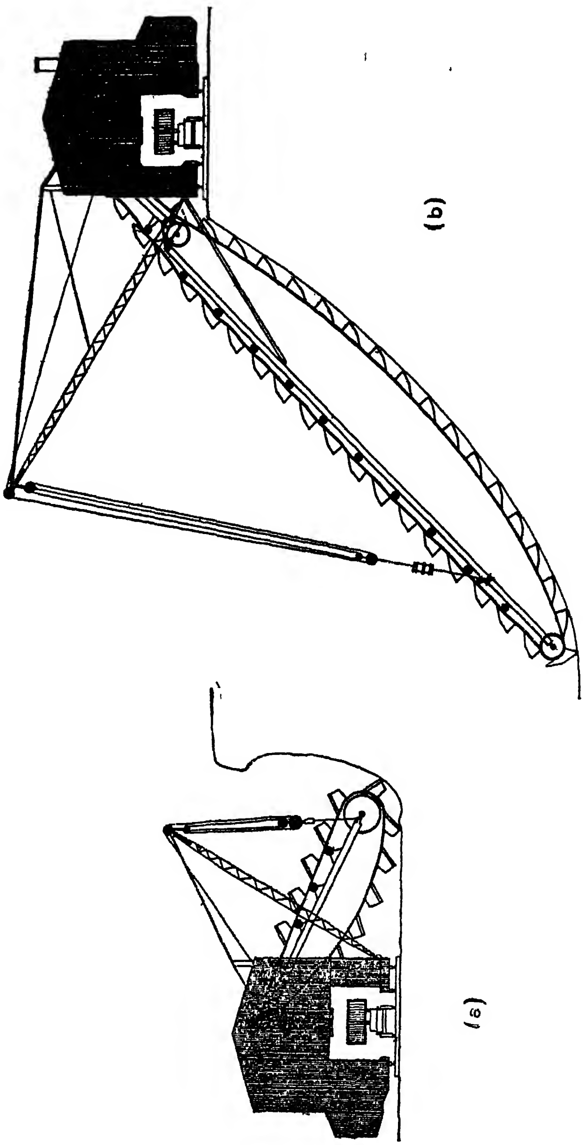



FIG. 52.—Lubecker land dredger.

that the route can be chosen so as to avoid the more costly rock excavations, consequently in general railway work the rock will be in many cases removed by hand drilling.

### HAND DRILLING

The bar used in drilling by hand is generally 6 or 7 ft. long and about $1\frac{1}{2}$ in. in diameter, the point being chisel-shaped and about 1 in. wider than the body of the rod, so as to leave space for lifting and lowering without any jamming of the hole. The hole is sometimes driven by "jumping" it, that is, by raising and dropping the rod about 1 ft. 6 in. or 2 ft. at a time, two men being engaged in so doing. After each blow the bar is turned slightly round in the hole so as to ensure that the chisel edge will strike on a new surface. Water is poured into the hole to keep the point of the tool cool and also to soften the rock. The rock is ground into dust or small chips, and the water "cakes" it, thus making it more easy to remove when cleaning out the hole. It is necessary that the hole be cleaned out frequently, as otherwise the broken material will retard the drilling operations, and this is done by means of a spoon-shaped scraper attached to the end of a thick wire.

The rate of progress of drilling rock by hand amounts to from 12 in. to 15 in. per hour, working in sandstone, limestone, or material of a like nature ; but in whinstone or igneous rock the rate will not exceed 6 in. to 8 in. per hour.

### MACHINE DRILLING

There are two distinct types of machine drills, percussion drills and rotary drills. In the former, the action may be said to be similar to that which exists in hand drilling, the hole being formed by repeated blows of a tool, but much more rapid than in hand drilling. In the rotary drill, the hole is formed by the tool drilling out the rock in a similar manner to the working of an auger in drilling wood.

The essential features of a good drill are that it should be of light description and easy to move from one place to another, simple in construction, avoiding complicated parts, thereby making it more easily mastered by the men at hand, compact, so that it can be used in restricted or confined situations, of perfect

workmanship, and consisting of materials specially suited for the particularly heavy work to which it is subjected.

Various types of percussion drills are made, but an example of Ingersoll-Rand Company's drill may be taken as typical of this class of machinery (see Fig. 53).

In this drill, the rod, head, and chuck are all in one piece, whereas if they had been constructed in separate pieces, there would have

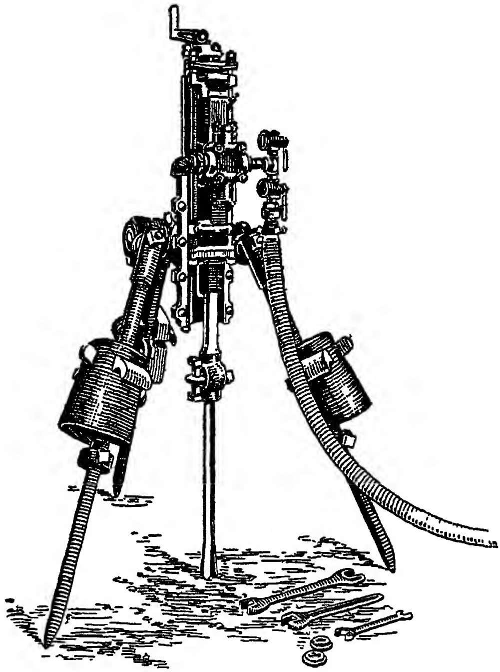


FIG. 53.—Ingersoll-Rand rock drill.

been a great tendency for the parts to become loose with the shock of 400 to 600 blows applied per minute.

In the best drills no cast iron is used, there being steel castings, tooled steel, malleable iron, drop forgings, and special metal where suited. The drilling tools are made of the best grade tooled steel to cope with the very severe work to which they are put.

In the cylinder of the machine there is no cushion pressure to retard the stroke and diminish the blow, and the blow is thus

absolutely "dead." The drill has a wide variation of stroke, which is secured by simply "cranking" the machine forward. This has great advantage when driving a hole on an oblique surface, and also admits of the hole being quickly started. The rotation of the rod is effected by having spirally grooved rod or rifled recesses in the back of the piston.

For the purpose of lengthening the bore as the work proceeds each tool has a set of drills. A fresh tool is put on the end of the piston rod as every few feet of depth are driven, and this allows of the drill just removed being handed over to the blacksmith for dressing.

Different types of drilling bits are in use for the various classes of rock to be cut through. In sandstone, a flat blunt bit gives the best result, while in an extremely hard rock, the X form gives the best results. In rock of an irregular texture, and where it is too hard for the flat bit, an X-shaped end is considered most suitable, as the probability of rifling or grooving the hole is more remote.

The best results in mechanical drills are secured with live active air in preference to steam, but the particular situation and the facilities obtainable will determine the method adopted. The working parts are somewhat different in the air and steam operated machines.

Where steam is used a considerable loss of power results if it is necessary to have long lines of piping. In general, steam is probably the most convenient and economical system, on account of the expense in providing compressed air plant. In recent years electricity has been introduced to operate the compressed air plant, and this is advantageous where long lengths of piping may be objectionable.

Rotary drills have not found favour on public works, and they are only mentioned here on account of the success which attended the driving of the Simplon Tunnel. The machine which was used there was worked by hydraulic power, the inventor and maker being Mr. A. Brandt.

Hand hammer drills operated by compressed air have lately been used (see Fig. 54). This machine was first used as a simple means of drilling shallow blast holes in boulders too large for removal by a steam digger or too heavy to be handled at a stone

crusher; but as no tripod or stand is necessary and as the hand hammer drill is easily handled and moved about, and can be operated in confined places where the tripod machine could not be worked, it is now extensively used. The cutting tools are either hollow, solid, or spiral-shaped. In hard solid rock where the drills cut freely the hollow tool is used, and by passing the exhaust air down the tube the debris at the foot of the holes is blown away

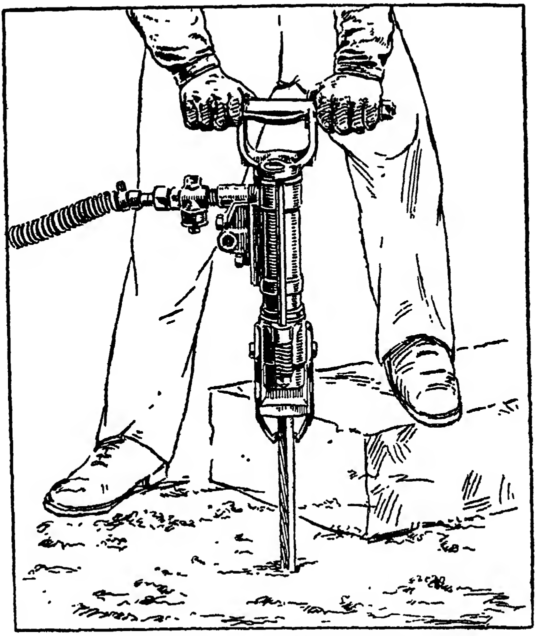


FIG. 54.—Hand hammer drill.

from the cutting edge. In soft rock, a spiral steel is used, the spiral acting as a conveyor for bringing the cuttings to the surface. Solid cutting tools would be used for driving "up-holes" where the broken rock in the hole would fall out.

The time occupied in drilling operations varies considerably with different classes of material. In granite the speed of drilling may be about 2 ft. per hour, whereas the speed in sandstone or limestone rock may be from 6 to 8 ft. per hour.

### BLASTING

The explosive agent used in blasting is determined by the character of the material to be dislodged, and whether it is proposed to make use of it for building purposes.

If no use is to be made of the rock for building and the material is being removed without any regard to the size or shape of the blocks, a high-grade explosive would be used if the rock should be of a tough description, such as whinstone or granite; but if the material should be a sandstone or a limestone rock, and where there is less resistance, a less virulent explosive would be more effective. If the material should be boulder clay, as in the case of breaking down a stiff cutting to feed a steam digger, the least virulent explosive is used, namely, black blasting gunpowder, or a low-grade granular nitro-glycerine. To get the best results, the percussive force of the explosive should be proportionate to the resistance of the material being removed.

If the rock has a commercial value and care has to be exercised in its removal, small charges of gunpowder would be used, the object being only to "shake" the rock and lift it from its bed.

In firing the charge, if there are only a few shot-holes, a powder fuse would be used; but if blasting is carried on extensively the charges would be fired by an electric exploder. Reference is made to the removal of rock in railway cuttings in Chapter IV, page 62.

### CONVEYANCE OF EXCAVATIONS FROM CUTTINGS TO EMBANKMENTS

The oldest and simplest method of taking earth in small quantities short distances is by means of a wheelbarrow. The barrow in general use is made of wood and has a capacity of about 4 cubic feet. Barrows may be conveniently used where the distance to be carried is less than about 150 ft., and to facilitate operations, planks of timber, or barrow tracks, are laid down on which to travel.

Wheelbarrows are also made of iron, but the wooden barrow is generally used on account of being more conveniently repaired.

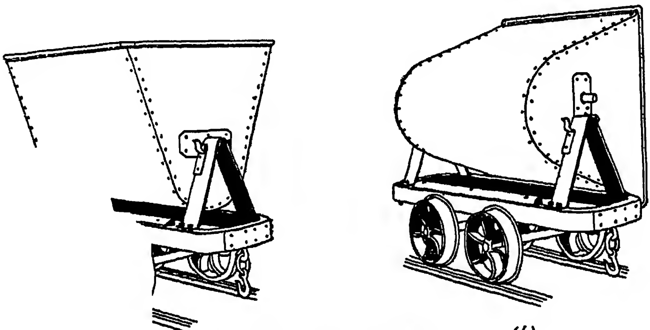
Where excavations have to be taken for some distance over firm ground, or along formed roads, horse carts are used. With fairly good roads, a horse can drag a cart up an incline of 1 in 10 for

short distances, and on a longer regular grade of about 1 in 12. In the cart in general use, the shafts are in one piece with the body of the cart, and to unload it the horse is detached from the shafts. Carts for removing excavations are sometimes made with the shafts and body in separate portions, thereby enabling the excavated material to be emptied without detaching the horse from the shafts.

The capacity of an ordinary cart is about 24 cubic feet.

### TIP WAGONS

For taking excavations short distances, iron tip wagons, running on a narrow-gauge railway, are sometimes used. These are of various designs, but a very convenient type is that illustrated by



(a) FIG. 55.—Iron tip wagon. (b)

Fig. 55. The usual size of this tip wagon has a capacity of 1 cubic yard, and travels on light rails placed 2 ft. 6 in. apart. The underframe of the car is in a separate piece from the body and has vertical frame supports at each end, on the sloping sides of which are jaws which engage two pins fixed on each end of the box. The pins are about 10 in. apart, and the box is held in position during transit by means of a catch pin which locks the box with the carriage; and while there is no possibility of overturning during transit, very little effort is required to tilt the box over and unload it.

It will be observed from Fig. 55 (*b*) that when the box is turned over the sloping side is in such a position as to allow the material to fall out without the assistance of any spade work. The wagon,

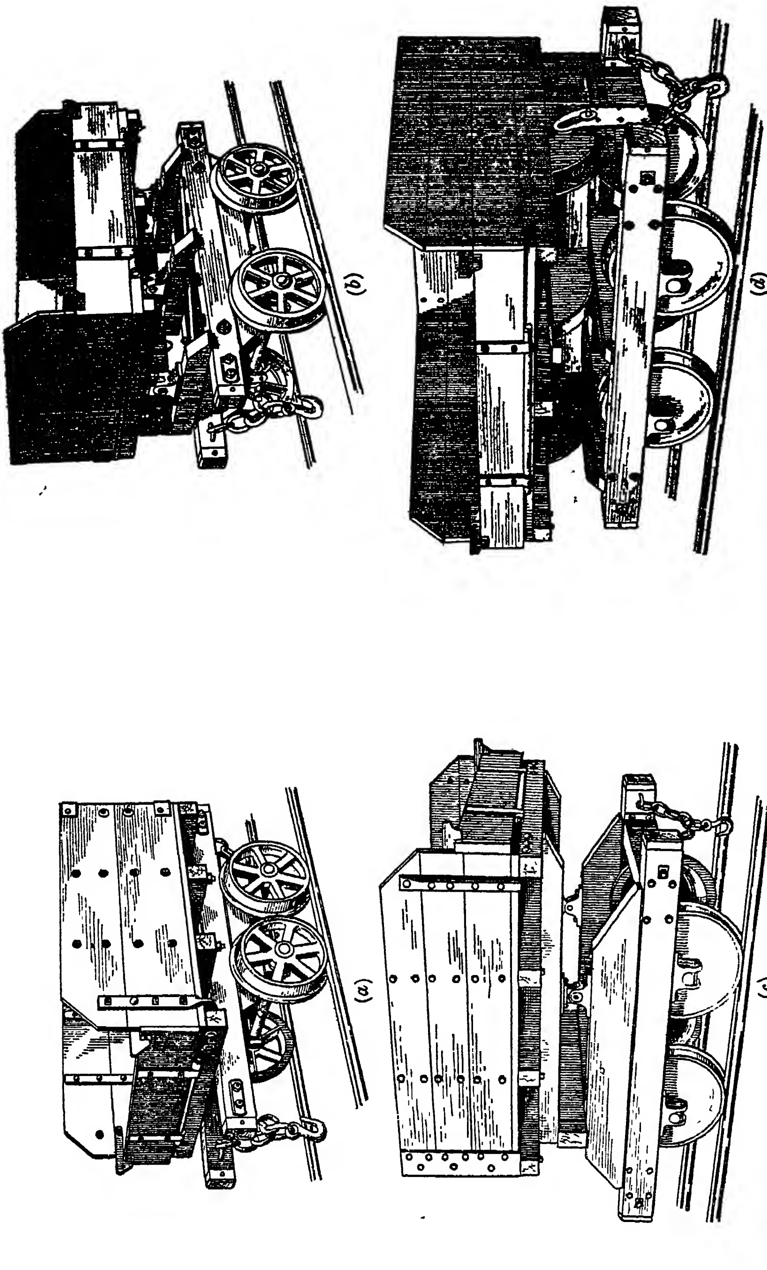



FIG —End and side tip wagons.
(a) One cubic yard end tip wagon.
' cubic yard side tip wagon.
(c) Four cubic yards end tip wagon.
r cubic yards side tip wagon.

when empty, is easily propelled along a level or up a flat gradient by a man pushing it, and when full, a horse can haul three or four wagons at a time along a level or up a slightly rising gradient. This type of wagon is largely used in countries where black or coolie labour is employed and where all the work is done by manual labour.

Several types of iron box tip wagons of somewhat similar construction to that above referred to are in use and are equally serviceable.

For ordinary railway work, flat-bottomed wagons are generally used. These are constructed both in wood and in iron, and are of varying capacities (see Fig. 56).

Where the "lead" to embankment does not exceed half a mile and where the material is being excavated by hand, 1-yard wagons running on a 3 ft. gauge railway are used. A rake of three loaded wagons can be drawn by a horse up an easy gradient. If a light engine is used for hauling the wagons more can be taken at one time, and gradients, if they are of no great length, as steep as 1 in 30 can be negotiated.

If the distance to be hauled exceeds half a mile, or if a steam digger is in use, larger wagons of, say, 4 cubic yards capacity, running on the standard railway gauge, may be used, and these are hauled by a locomotive. Wagons can be had with either side tip or end tip action. The question of side tip as against end tip wagons is referred to in Chapter IV, page 60.

Where excavated material has to be taken over existing lines of railway in removing it from the cutting to embankment, it will be conveyed in wagons provided with springs and buffers similar to the rolling stock of the railway on which they have to travel.

## DRAG AND WHEEL SCRAPERS

A method largely used in America for removing excavations from railway cuttings in open country is by means of drag and wheel scrapers.

The object of these machines is to remove the material from the place of excavation, drag or wheel it to and tip it at the place of embankment.

Previous to the material being conveyed from the cutting to

embankment the surface of the ground is, unless the material is of a very loose description, broken up by a plough. In ordinary earth the plough is hauled by two horses and two men are employed, a driver and a ploughman. If the material is of a hard description, the plough is weighted.

### DRAG SCRAPER

For short leads of from 100 to 200 ft. a drag scraper is used. The drag scraper, or "slusher" as it is sometimes called, consists of a scoop-shaped iron box with a cutting edge, the capacity of it being about 5 cubic feet.

Fixed near the front and to either side of the box by a pivoted connection is a bent rod which forms an attachment for a team of horses to drag the scraper over the ground, while at the back there are handles to guide it when it is being filled and emptied.

When it is desired to fill the box it is tilted up slightly by raising the handles when being dragged along the ground. The sharp edge cuts into the ground and the earth is scooped into the box. On the handles being released the box takes up its original position, and the box of earth is hauled to the tip. To empty it the driver again lifts the handles and with the sharp edge cutting into the ground the box is suddenly pulled up, which causes it to turn on the pivots at the connection of the drag link, with the result that the earth is thrown out.

A team of horses is required to haul the scraper, and the driver usually empties it, other men being employed for the filling operation and also for the levelling of the ground at the tip. Where the material is of a light description the driver of the team may also do the filling.

### WHEEL SCRAPER

Where the lead exceeds 200 ft. the wheel scraper, or "wheeler." is used. The principle of it is the same as the drag scraper, but being a larger box it is carried on wheels. By means of a lever attachment the box can be tilted up to be filled or lowered as required. The average capacity of the box is about one-half cubic

yard. The wheel scraper is drawn by two horses, although it is usual to employ another team, known as a snatch team, to assist in filling the box. Where ordinary soil is being removed, it is usual to employ one man extra to the driver, but in heavy soil it is customary to employ two extra men for the purpose of filling.

# CHAPTER VI

## SLIPS IN EARTHWORK AND THE MEANS TAKEN TO PREVENT THEM

The importance of being fully informed as to the character of the materials likely to be met with in executing earthwork, and the necessity for thorough drainage works being provided have already been referred to, but the bearing of these matters on the ultimate success of the undertaking will be better appreciated when questions relating to slips have been considered.

### CHARACTERISTICS OF VARIOUS MATERIALS

Slips in earthwork are due to the resistance between the particles or between plane surfaces in contact having been overcome. The tendency of all materials is to take up a horizontal position, and the fact that one material will stand at a steeper slope than another is due to that material having a greater frictional or cohesive resistance. The slope at which a material will stand relative to the horizontal is termed the angle of repose of that material.

Clean dry sand or gravel is supported by the frictional resistance between the particles or stones, while, on the other hand, clay is almost entirely supported by the cohesion of the mass.

A moderate amount of moisture or water helps to support earthwork, but if there should be an excess of water the resistance to movement is very considerably reduced. With a fine dry sand there is no cohesion between the grains when in a perfectly dry state, but with the presence of moisture or dampness cohesion is established which enables the sand to stand at a steeper slope than it would otherwise do. If there is an excess of wetness the sand will not stand except at a very flat slope. The larger the particles or the coarser the sand the steeper will be the slope at which the sand will stand.

In the case of clay, the presence of moisture very largely assists the stability, but an excess of water will dissolve the clay and destroy the supporting power. Pure clays are dangerous on account of their stability being so much reduced by water. Certain clays are so hard that they require a pick to excavate them, but after continuous exposure to wet weather they get so soft that they will only stand at a very flat slope.

The stability of a soil thus depends on the effectiveness of the means taken to protect the material from or to remove any superfluous and consequently dangerous water. At the same time it must be kept in view that all clayey soils require a limited quantity of moisture for their stability, and that by exposure to the atmosphere the moisture may get dried out and the supporting power of the clay become reduced in consequence. The expansion of clay when wet and the contraction in dry weather are also responsible for considerable damage to earthwork.

The following are given as the slopes at which earthwork will stand under ordinary conditions :—

| | | | | |
|---|---|---|---|---|
| Gravel | 1 | horizontal to | 1 | vertical. |
| Dry sand | $1\frac{1}{4}$ | ,, | 1 | ,, |
| Compact earth | $1\frac{1}{2}$ | ,, | 1 | ,, |
| Clay, well drained | $1\frac{1}{2}$ | ,, | 1 | ,, |
| Clay, wet | 3 to 5 | ,, | 1 | ,, |

In a rock cutting the slopes will range from $\frac{1}{4}$ to 1 to 1 to 1, depending on the character of the material. Certain material, such as faikes or fireclay, may be very difficult to remove from a cutting, but after weathering may require to be trimmed off to a slope of $1\frac{1}{2}$ to 1.

The above figures should only be used as a guide, and in determining what slope the material will take regard must be had to the actual conditions prevailing and the experience obtained under similar circumstances, in view of the fact that the stability is so much affected by atmospheric conditions and slight changes in the character or composition of the material.

The character of the materials in the cuttings and the slopes which it will be necessary to adopt as well as of the material to be put into embankment should receive full consideration by the Engineer as otherwise serious trouble may afterwards result. The

possibility of flatter slopes being required than would at first sight appear necessary should be fully considered before the construction of the works is proceeded with.

### SLIPS IN CUTTINGS

Slips in cuttings are either due to the action of water flowing off the surface of the adjoining lands, water in the strata cut through, to rainstorms or water in the form of moisture in the atmosphere, or they may be due to the taking away of the natural support by the removal of material which was necessary to maintain a state of equilibrium.

As regards slips caused directly by the action of water, the

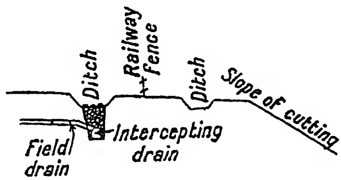



Fig. 57.—Drain for intercepting field drains and surface water.

resulting damage may consist of the loosening and gradual crumbling away of the surface of the slope and the falling in of the portion above for want of proper support. The water may have come on to the slope on account of the surface or agricultural drainage of the land not having been properly intercepted, or it may have percolated through the strata. As already stated, the necessary drainage of the adjoining lands should be executed prior to the excavations in the cutting being proceeded with.

For the purpose of intercepting surface water it is usual to have an open ditch cut on the high side of a cutting immediately outside of the railway fence (see Fig. 57). If there are any agricultural drains which would be interfered with in forming the railway cutting these should be intercepted by laying a drain immediately outside of the railway fence, which would either discharge into a pipe laid down the slope of the cutting and connected with the drainage of the formation of the railway, or be led entirely clear of the railway. It is usual in laying this drain to leave the track which has been

cut for it unfilled for the upper 9 inches, thereby forming a ditch to catch the surface water. Agricultural drains will probably be about 2 ft. or 2 ft. 6 in. below the surface, and the intercepting pipe would be a 6-in. or 9-in. fireclay pipe with open joints, the joints being surrounded by broken stones which would be carried up the trench to within 9 inches of the surface. The agricultural drains would be led into this main drain either by branches on the main drain or by forming an opening in the upper surface of the pipe. If the material in which the drains are laid is of a clayey description it would be well to form the lower half of the joints of the intercepting pipe with cement, so as to have a watertight channel, and thereby prevent water finding its way into the slope of the cutting.

There is a danger of water from the surface of the adjoining land which flows into an open ditch finding its way into the substrata, and thereby causing damage to the slopes of the cutting. It is thus necessary that consideration be given to the character of the material in which any ditch or surface catch-water drain is being formed, and if any danger is feared it is better that the surface water should be allowed to flow freely down the slope of the cutting into the formation drains. Where open ditches are formed they should be periodically inspected and cleaned out, so that no damage may result from obstruction.

If the water is coming through the strata it may have been impossible to have known of its existence or to have made any provision for its removal prior to the cutting being excavated, but as soon as it is observed when the cutting is in progress no time should be lost in dealing with it. The source of water appearing in the cutting should be immediately investigated, and, if it cannot be traced and intercepted either at its source or at some distance from the cutting, the water should be conducted clear of the excavation operations. In the event of water appearing on the slope in small quantities or at a few isolated points, it may only be necessary to lay rough stone pitching over small areas and lead drains therefrom down to formation of the road or railway cutting. An important point to observe is that when a drain is laid to carry away water which may collect in stone pitching or in dry filling it should be placed in the bottom of such pitching or dry filling, and thus prevent damage by water collecting at a lower level.

Not infrequently springs are tapped in forming a cutting, and these may be effectively dealt with by inserting a pipe in the slope and leading the water to the surface, or if this is not sufficient, the source of it may be traced by digging a trench and conducting the water safely clear of the slope. No attempt should be made to dam back or check the flow, or retard the free discharge of water appearing in a cutting, as otherwise it is certain to break out at some other point in a much more aggressive manner.

As a general rule the water would either be intercepted by laying a drain at the level of the porous strata outside of and well clear of the top of the slope of the cutting, or it would be allowed to come to the face of the slope and be conducted by means of drains down to formation level of the railway. To intercept the water before it reached the slope might, unless the bottom level of the stratum which contains the water is near the surface, prove to be very costly, but if properly carried out it will be the more effective method, and, keeping in view the future maintenance of the work, it will probably prove the more economical in the end.

Where maintenance work of the description of keeping slope drains in order is required, the subsequent remedial work to maintain them in a satisfactory state of repair is frequently delayed or overlooked and indifferently executed, and it is thus better that as little water as possible be allowed to percolate through to the surface of the slope.

The water appearing in the strata may be traced to a natural deflection of the surface of the ground, and situated some distance from the top of the slope, or the outcrop of the water-bearing stratum may be ascertained from the inclination or "dip" as seen from the level of the two sides of the cutting, and in either case, it may be much less costly to lay a pipe to drain the natural hollow or intercept the water in the stratum by a much shallower drain at some distance from the cutting, than would be necessary if the drain were formed immediately behind the top of the slope.

The following example will illustrate the manner in which work of this description has been carried out. In taking out the excavations of a railway goods yard, which was about 25 ft. deep, a considerable volume of subsoil water was met with a few feet below the surface of the ground. The material in the cutting was of a fine sandy description with a proportion of clay mixed

with it, and as long as it was dry or contained only a small quantity of water it was quite good for embankment purposes, but with the large volume of water that was met with in the lower part of the cutting it was rendered altogether unsuitable.

The material was being taken to an embankment about three miles distant, and, on account of the water in the cutting, the excavated material was converted into slurry, and the service roads were very expensive to maintain in proper order by reason of the drippings from the wagons, and the cost of tipping the excavations at the embankment was also excessive. It was thus necessary that the water should either be intercepted before it reached the cutting face or that the material with the water in it should be run to spoil embankment.

All the excavations from the line and station cuttings were required for the purpose of making up the embankments, and, if the material in question had not been available, side cutting would have been necessary, and this would have entailed at least double the cost in removal. It was therefore decided to intercept the water before it got to the cutting, and this was done by laying a drain below the level of the formation of the yard. In executing the work it was necessary to close-timber the sides of the trench and lay each pipe and form the joints under the constant inrush of water and silty sand. All field drains cut through in laying the main drain were connected to the main drain and the pipe was led to a proper outfall. The joints of the pipes in the main drain were thoroughly packed round by stones, and the trench up to the level of the water in the stratum was also filled with broken stones. The result was entirely satisfactory and the excavations were removed and deposited in embankment without further trouble.

In work of this description the most convenient drainage outlet may be by a drain or several drains led down the slope of the cutting which would discharge into a pipe laid along the formation of the railway.

When the water in the stratum is allowed to come to the surface of the slope (see Fig. 58) a complete system of drainage will be necessary. Main drains would be laid square to the line of the cutting, while diagonal and branch drains would connect with them as shown. The size of these drains and the distance apart would depend on the quantity of water to contend with and the character

of the material in the excavations, but in ordinary circumstances and with fairly solid material in which to form the drain, the main drains would be placed from 20 to 30 ft. apart, and be 2 ft. wide by 2 ft. deep, or deeper if necessary in order to get a grip of the firm ground underneath.

The drain would consist of a pipe preferably with spigot and faucet joints surrounded on both sides and on the top with broken stone carefully hand packed in the trench. If the ground in which the pipes are laid is of a clayey description the joints would be formed as already described, with clay or cement for the lower

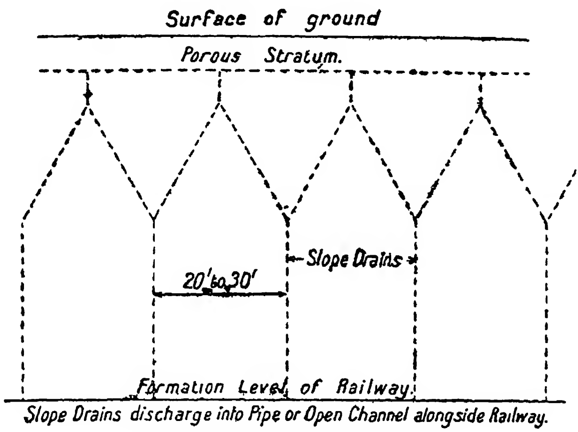



FIG. 58.—Slope drains in cutting.

half, so as to prevent leakage of water which would cause damage to the ground underneath, and the trench would be made up on both sides of the pipe to the same level as the clay or cement of the joint, with clay well rammed in. In good ground, such as firm sand or gravel, or with certain kinds of clay, where any little leakage from the drain is not injurious to the slope, it would be sufficient to lay an open-jointed tile drain surrounded by broken stones, but in a soft material or material which is easily turned to silt or slurry by the action of water, the method referred to would be adopted.

It is necessary, in forming slope drains, that the drains and broken stones be laid immediately after the track has been cut,

as otherwise the sides of the track may fall in and seriously damage the portions of the slopes on either side immediately adjoining. In addition to taking away the water which appears on the slopes, the drains so formed will be helpful in supporting the portion of the slope between each of the main drains. These drains would, of course, not be laid until the slopes of the cuttings had been formed, but in view of the importance of keeping the embanking material as free as possible from water, it is most essential that any water met with should be temporarily led away in pipes or timber troughs or other channels while the excavation work is in progress and before any damage can result to the slopes.

When the slopes of the cuttings are subsequently being soiled, care should be taken by covering the drains with bags or otherwise to ensure that the soil is not allowed to mix with the broken stones, and thereby reduce the efficiency of the drains, and for the same reason the broken stones should be carried up to the level of the surface after the slopes have been soiled.

In addition to the main and diagonal drains patches of pitching may be necessary to drain any soft portion of the slope that may have a tendency to slip. It is better that the diagonal drains should not be laid with too flat an angle as there would be a tendency for the soil on the upper side to choke the drain, and there is also a liability for the drains to become distorted and leak when any slight movement of the surface takes place, thereby causing the material on the lower side to be washed away and the drain ultimately to become destroyed for want of support. A very satisfactory result, and that with little extra expense being incurred, is obtained by placing a layer of turf along each side of the drain and at the level of the soiling, the turf being held in position by wooden pegs if there should be a tendency for it to slip on the slope.

The slopes of a cutting are never thoroughly satisfactory until they have been soiled over and sown down with grass and a good tough sward formed. The roots not only form a binder to assist in sustaining the material, but they are also a protection against wind on a sandy surface, and against rain, which will damage a clayey, sandy, or other surface, in which the material, when saturated with water, has a tendency to "run." If it is considered necessary, stronger roots can be obtained by sowing the slopes

with whin or broom seed, in which case a very firm deep-rooted covering is obtained.

In the case of cuttings which consist of certain kinds of clay, where the material, when protected, will stand at the usual slope of 1½ to 1, what is wanted is more of a covering with close binding roots, and where water falling on the surface will drain freely off, and in such cases whin or broom would be objectionable. In sowing slopes it is necessary that the work be executed at the proper season of the year so as to ensure a good growth being formed before wintry or otherwise inclement weather. To maintain the slopes in good condition the grass or broom should be cut periodically. While it is right that the slopes should be dressed to

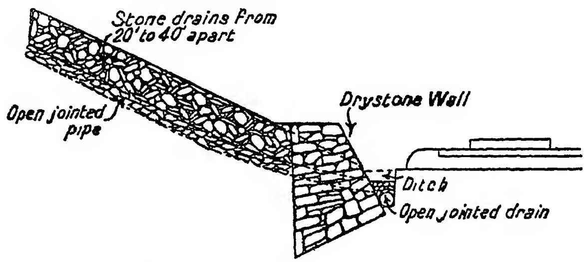



FIG. 59.—Large slope drains with toe wall at foot of slope.

a regular batter, it is a mistake to have too smooth a surface, as the soil may get washed off by the first rainstorm and before the roots of the grass covering are developed.

When the excavations consist of soft clay or other material which, when in its natural moist condition may stand at a slope of 3 horizontal to 1 vertical, but when saturated with water may run to slurry, more expensive works than those referred to will be necessary. The action of rainstorms on slopes of this class of material, even after being covered over with grass, may be most destructive. In dry weather the surface gets cracked and open which gives access for water in wet weather, thereby causing the damage. When adjoining property is valuable and where the cutting is not more than a few feet deep, it may be more economical to build retaining walls for the full depth of the cutting. If the adjoining property is not expensive the material might be allowed to take its own slope.

If the cutting is over a few feet in depth, while the cost of the land may not be of serious moment, to allow the material to adapt itself to a natural slope might, owing to the configuration of the ground, be entirely out of the question, and with the view to bringing the work within reasonable limits it may be decided to drain the slope in a somewhat similar manner to that already described, but on a larger scale. Drains of from 4 to 6 ft. wide and from 2 to 3 ft. deep placed from 20 to 40 ft. apart would be constructed (see Fig. 59) with a toe wall carried along the foot of the slope continuous between the drains. The stones used for these drains should be fairly large but not too heavy, otherwise the soft slope would not be able to support them; but, on the other hand, they should be such that the pressure of the material behind will not

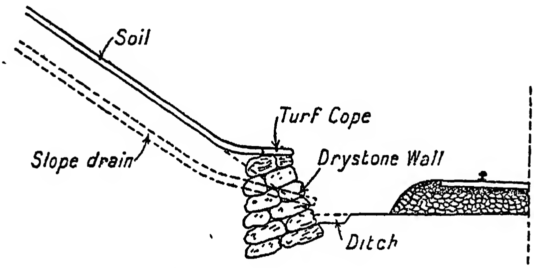



FIG. 60.—Drystone dwarf wall at foot of slope.

force them out of place. If the clay from the cutting of the drains is suitable, it would be burned and the clinker used for filling the drains, or old slag ballast or other light material would be very suitable. To protect the exposed clay from the effects of warm weather and subsequent rains, it should be covered over with ashes, gravel, or similar material to a depth of at least a foot, and afterwards soiled over.

The method adopted for dealing with slipping material in clay cuttings is largely determined by the cost of removing the material and forming drains and revetment walls, together with the cost of the land, as against the cost of building substantial retaining walls.

In all cuttings through material other than rock the toe of the slope alongside formation would be protected from erosion by water flowing off the slope and running alongside formation. In very

shallow cuttings a turf border 18 in. broad laid in two thicknesses may be sufficient, but where over a few feet in depth it is usual to form a drystone dwarf wall (see Fig. 60). The deeper the cutting is the greater will be the volume of water running off the slope in wet weather, and consequently there is the greater necessity for the toe of the slope being well protected in deep cuttings. If a wall is constructed ample provision should be made for the free passage of water through it, and a drystone wall would thus be preferable to a wall built with cement, where the wall is of a less depth than 5 or 6 ft. Where the wall is built with cement a thickness of 12 or 18 in. of drystone backing should be placed behind it, with proper connections made to the drainage outlets in the wall. These outlets or weep holes should not be more than

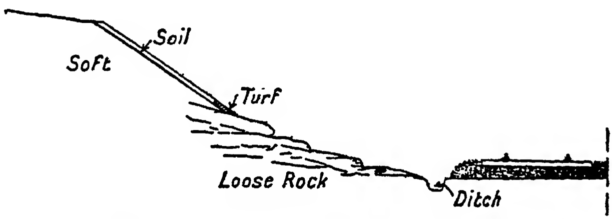



FIG. 61.—Flat slope in loose rock cutting.

about 9 in. below the finished level of the rails adjoining, so as to ensure that there will be no obstruction at the outlet en pipes.

Slips in rock cuttings are generally due to the inclination of the beds of stratified rock which may be such that when cut through the portion on the upper side of the "dip" falls away for want of proper support, and, if water should have found its way into the strata, there will be the greater tendency to slip.

Slips are of most frequent occurrence in strata consisting of thin layers of limestone or faikes intermixed with bands of clay or silt. Overlying this there may be a porous stratum, from which water finds its way through the fissures in the rock until a solid impervious stratum is reached. When such material is cut through the water will trickle down the face of the cutting over the exposed ends of the strata, washing out the beds of clay or silt near the face, and thereby undermining the thin layers of rock overhead, which will ultimately fall in. Changes of weather, frost, thaw, and rain, will

assist this disintegrating action. While the presence of water considerably hastens the destruction, atmospheric influences alone would slowly cause the exposed face to corrode, and unless otherwise protected it would probably be necessary to take out the excavations to a slope of 1½ to 1 if the beds of the strata are level, and if they should be at even a very slight inclination it may be necessary to finish off the slope by stepping back the broken rock to a batter of perhaps 2½ to 3 to 1 (see Fig. 61). If it should be necessary to flatten the slopes beyond what was originally intended additional land will have to be acquired or face walls of sufficient height built to keep the top of the slope within the limits of the original ground. The method adopted will altogether be decided

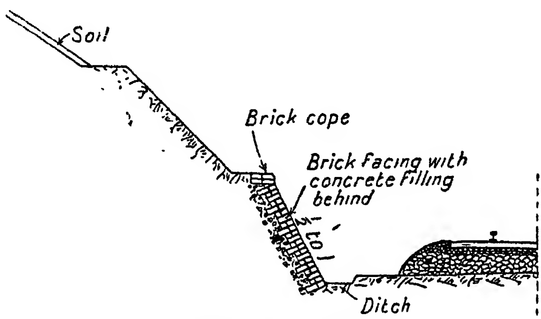



FIG. 62.—Face wall in rock cutting.

on the question of expense, and in considering the matter it must be kept in view that it will be less costly to maintain a retaining wall than a slope which may require frequent attention.

When on account of the character of the material it is necessary to excavate the rock to a 1 to 1 batter or to a flatter slope, a covering of grass will prove a sufficient protection from the action of the weather; but, if the material will stand at a steeper slope without risk of sliding, a face wall would be constructed, ample provision being, of course, made for free drainage of any water that may collect at the back of the wall. Figs. 62 and 63 illustrate a face wall and a retaining wall respectively to protect or support a rock cutting.

As regards the treatment of slips, no hard and fast rule can be laid down, as each failure must be dependent on the particular

circumstances that surround it. By noting, however, the means generally adopted and the manner in which special cases are dealt with, a method of procedure may suggest itself.

When considering the means taken to prevent slips the necessity for thorough drainage was pointed out, and the inefficiency of these protective measures is very largely responsible for the slipping of material in slopes. It will be obvious that by giving due consideration to the question of drainage much of this trouble may be averted, but it must be admitted that serious damage may occur by circumstances that could not have been foreseen. It is necessary to emphasize the importance of frequent observations being taken if

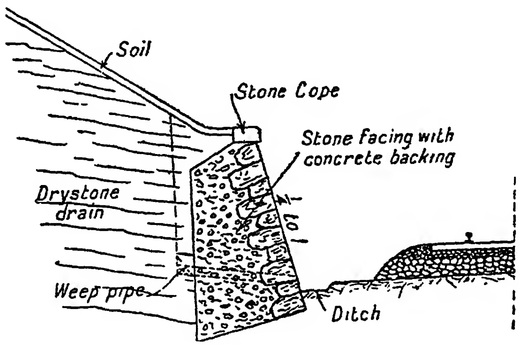



FIG. 63.—Retaining wall in soft rock cutting.

there is any probability of a slip taking place, and when any water appears or collects on the ground or when there is the slightest indication of a movement in the ground, the warning should not be neglected, but instant steps taken to avert what might mean very serious trouble. These remarks apply equally to slips in embankments as well as in cuttings.

When a slip does take place in a cutting endeavour should at once be made to divert any water that may flow into the back of the moving material, and such temporary work as the lightening of the upper portion of the disturbed mass and the supporting of the unmoved ground behind should also receive immediate attention.

When the damage done is of small dimension the slipped material should be cleared out to the bottom (see Fig. 64), following on which the surface underneath should be covered over with large

stones, carefully hand placed, and a drain laid therefrom to the ditch or water channel which runs along formation. Quarry shivers or old slag should afterwards be placed on the top of this layer of stones and brought up to the level of the surface of the slope; the upper surface should thereafter be blinded with finer material and finally soiled over and sown down. Care should be

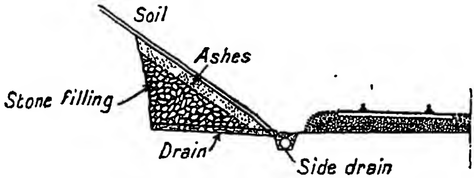



FIG. 64.—Slip of small dimensions in cutting.

taken to ensure that the stone filling is built close up to the back of the slip, and any water in the exposed stratum should have free drainage to the drain pipes leading to formation of the cutting. Surface cracks which may subsequently appear, due to settlement or after heavy rains, should be made good with a view to preventing further damage. If the material under the slip is of a soft description, the filling in should be of a light character.

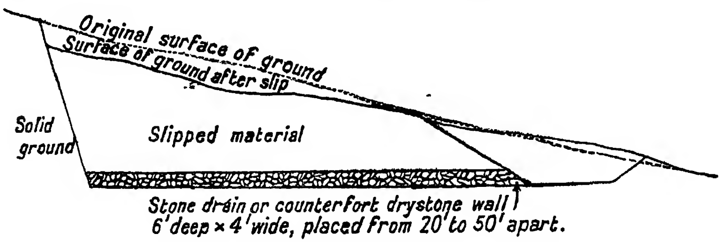



FIG. 65.—Slip of large dimensions in cutting.

More extensive slips may be due to the complete saturation of the materials in the slopes and the consequent tendency to take up a horizontal position. In such cases an attempt should be made to restore the material to its original stable condition by constructing heavy slope drains and forming a strong toe wall in the manner already referred to for dealing with soft cuttings. In certain strata it is a common occurrence for the slipping material to come away from the solid ground in a plumb face (see Fig. 65). The

strata may consist of clay with thin layers of sand interspersed, or it may be beds of limestone and faikes or clay in alternate layers, and the movement will probably be caused by water percolating through the sand or open joints of the broken rock, saturating the clay bed and converting it into silt or slurry. Slips of this description have been successfully treated by constructing stone drains or counterfort drystone walls at right angles to the line of the cutting. The trenches for the walls would be cut down to and into the solid ground underneath and carried to the solid ground at the back of the slip. These walls when formed will act both as a carrier for the removal of water and as a support for the unmoved ground behind. The width and distance apart of these walls will depend on the character of the slipping material and the depth of the slope; but in general they might be from 4 to 6 ft. wide, and from 20 to 50 ft. apart. There is a danger of having them too far apart, as each portion of the slope between the walls may have a tendency to slip of itself. Surface diagonal slope drains, 2 or 3 ft. square, may be laid between the walls to consolidate the ground more effectively and prevent further slipping; but if the slope has been very badly shaken it may be necessary to turn over the whole of the material between the walls and compact it by wheeling and punning, and the surface should thereafter be covered with a bed of ashes under the finished coating of soil so as to protect the clayey material underneath from the ac[illegible] weather.

To further support the slope a drystone wall should be constructed alongside formation, connecting the ends of the counterfort walls, through which the drains from the slope would be carried into a main drain laid alongside the track. If the excavations from the drains should consist of suitable material it may be economical to burn it into clinker for use in the walls and drains. In the event of the damage being caused by surface water, a pipe would, as already stated, be laid as soon as the slip is observed to divert the water; but if the water is in the strata, it may be advisable to lay a drain clear of the slip in addition to the other remedial work referred to.

The following is an instance wherein circumstances necessitated special treatment (see Fig. 66).

The cutting was for the construction of a railway and had a depth

of 29 ft. measured on the centre line; but by reason of the inclination of the surface of the ground, which was about 4½ horizontal to 1 vertical, the vertical depth from the top of the slope to formation level was about 70 ft. The material cut through consisted of moss for the first 5 ft., underneath which it was of a greasy clay until formation was reached, when faiky fireclay was met with. The material was being excavated to a slope of 1¾ horizontal to 1

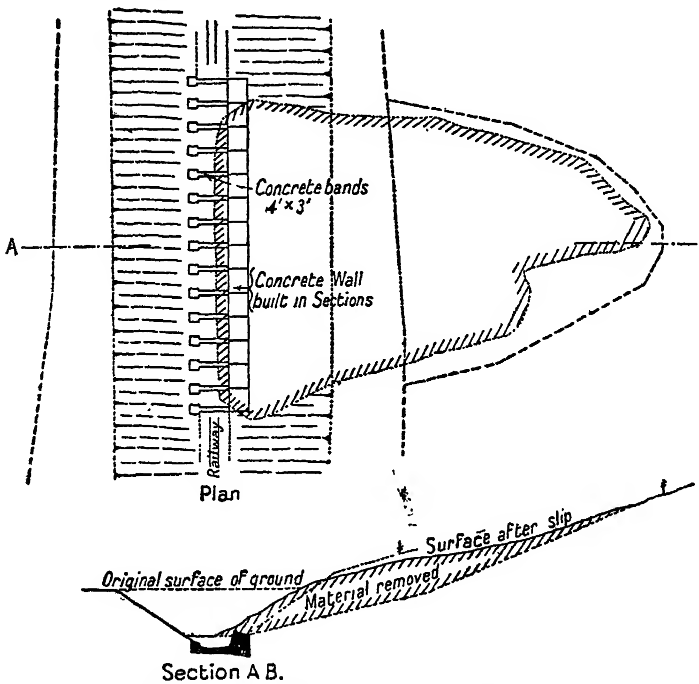



FIG. 66.—Slip in cutting requiring special treatment

vertical, and the cutting had been excavated to within 5 ft. 6 in. of the formation level, the slopes being dressed off to the finished batter immediately behind the steam digger, when without any previous warning the ground on the high side gave way. The plane on which the mass of clay was sliding was inclined at about 2½ to 1, and the disturbed ground extended for a width of about 165 ft. outside of the top of the slope.

Arrangements were at once made to remove the whole of the

slipping material, and simultaneously a concrete wall was built in trenches for the support of the lower portion of the cutting which had not yet been removed. The wall was built in sections of 12-ft. lengths and was carried on from both ends and at varying stages of progress so as not to disturb the unmoved ground behind, and, as a protection against the wall being pushed out after the lower portion of the cutting had been removed, bands of concrete were carried across formation to the foot of the opposite slope. After the slipping material had been removed and the rough edges round the slip dressed off to a regular slope, the area was soiled over and sown down.

The following special measures were adopted in excavating a railway cutting where a large volume of subsoil water was present,

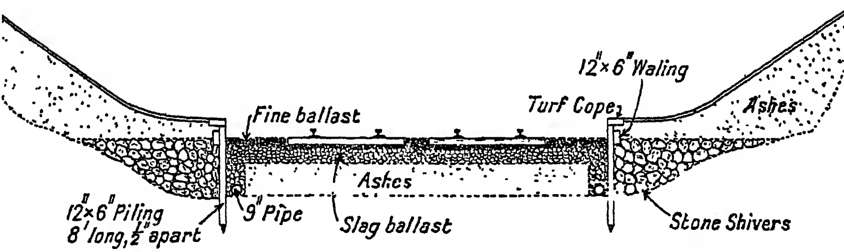



FIG. 67.—Section in cutting with large volume of subsoil water.

which will illustrate the means adopted to prevent subsequent slipping (see Fig. 67).

The cutting was 43 ft. deep, and the stratum consisted of fine sand and contained a large volume of water. As the work proceeded the water in the sand was lowered until it reached a level of about 6 ft. above formation level of the railway, below which the material consisted of fine sand and mud, of a very wet consistency. The cutting was taken out to a depth of 2 ft. below formation level and a row of sheet piling was driven along each side of formation. These piles were 8 ft. long, 12 in. broad by 6 in. thick, and were driven so that they would have 4 ft. of a hold below the level excavated, and to allow of water getting through from behind, a distance piece ½ in. thick was fixed to the side of each pile. The space at the back was filled with stone quarry shivers and covered over with ashes.

At certain points the flow of water in the sand behind the piles was stronger than at others, and at these places open-jointed fireclay pipes were laid and carefully surrounded with stones. The space, which was taken out 2 ft. below the formation level between the fronts of the two rows of piles, was filled up with ashes, and a 9-in. open-jointed pipe was laid along the front of the piling on each side of the railway and covered over with broken stones. The slag ballast of the railway was carried level across between the piling and this assisted the keeping of it in position. The slopes of the cutting were afterwards dressed and soiled and sown down with grass seeds, a double turf cope being laid along the top of the piling. As indicative of the quantity of water met with, it may be remarked that each of the 9-in. pipes was running half full for a considerable time after the work was executed.

### SLIPS IN EMBANKMENTS

Slips in embankments are either due to the character of the material of which the embankment consists or the condition of the ground or of the substratum under the site of the embankment.

As regards the former, while the description of the material as it appears in the cutting is the primary consideration, the manner in which it has been removed from the cutting and deposited in the embankment, together with the weather conditions when the work was executed, may be very largely responsible for the stability of the work.

From an economical point of view, it is generally desirable that the quantities of the cuttings and embankments should as nearly as possible balance, but an embankment must not be endangered by depositing other than the most suitable materials, and consequently all wet sand, mud, moss, or material of a similar description should be run to spoil.

By reason of the fact that the cohesion of the material which existed in the solid cutting has been largely reduced when the excavations were being removed, the supporting power of the embanking material immediately after it has been deposited is for the most part obtained from the frictional resistance between the particles or pieces forming the mass. The original cohesive resistance can, however, in a large measure be restored if care is taken

in depositing the excavations in embankment; but in view of the vibration caused by suddenly applied loads such as occur on railways, it is not desirable to put too great reliance on the additional stability so obtained.

In forming an embankment water should, as far as possible, be kept clear of the operations in the cutting from whence the material is obtained, and precautions should also be taken to prevent any lodgment of water on the surface of the embankment. A good deal depends on the time of the year when the work is being executed, but neglect in making proper provisions for drainage is accountable for many slips in embankments. A little rain will assist in consolidating an embankment, but a continuous spell of wet weather will tend to cause slipping.

When operations are resumed after having been suspended on account of inclement weather, clayey material which has been converted into slurry at the point where excavations were proceeding, as well as similar material on the surface level of the embankment where the excavations are being deposited, should be removed and run to spoil. If the operations have been conducted during a very dry season, moisture in the excavated material will be dried out, with the result that when wet weather sets in damage may be caused by reason of the swelling of the mass. Sand or gravel, or similar material, will be much less affected than clay, faikes, or material of a like description in which the p are dissolved by water. In clay embankments fissures and c which are formed during a dry season should be filled up so avoid damage when wet weather sets in.

When the excavations consist of hard clay, or boulder clay, it may be advantageous to loosen it by blasting immediately ahead of where the steam digger may be working, and there will probably be large lumps of material which, if tipped into the embankment without first having been broken up, will cause trouble, as surface water will get into the crevices, the clay will soften, subsidence take place, and finally a serious slip may result. When the material is being deposited, the larger pieces of it roll to the bottom of the slope, and if these should consist of large stones or pieces of rock they will assist in maintaining the toe of the slope; but if they should be pieces of clay, instead of acting as a support they will cause serious trouble.

Embankments of earth should be as homogeneous as possible, and this is best obtained by bringing them up in several layers when they are being formed in the manner already described. The advantage to be gained in using side-tip wagons in preference to end-tip wagons in forming wide embankments has already been referred to. A method which has been successfully adopted in constructing wide banks is to tip a narrow bank of good material at the extreme outsides and afterwards fill in the centre portion with whatever material was available; but this departure from the recognised principle of running bad material to spoil should only be resorted to when suitable embanking material cannot otherwise be obtained.

When various classes of material are put into the same embankment, or when the work is carried on during different kinds of weather, some parts of the embankment will be more compact than others, and consequently there will be a want of proper homogeneity, with the result that there will be a tendency to slip. It may be very difficult to obtain the same material to fill a large embankment throughout. Several cuttings may be required to make up one embankment, and even the material in a large cutting may vary considerably at different points, but if it is carried up in layers, thus ensuring that each layer consists of the same material or is executed during the same season, there will be less chance of damage from that cause.

It is essential that the slope of the embanking material be not made steeper than the slope to which the cutting from which the material has been removed has been formed, and it is also necessary that the slope should be sufficiently spread out so that the unit pressure at the base, both on the material in the embankment and on the ground on which the embankment rests, will not be too great. It will be recognised, however, that it may be harmful to make a slope too flat, for the reason that a larger surface is thereby exposed, and also that by reason of inequalities in the surface which occur in any slope and cause saturation of the material. It is usual in high embankments to form the upper part with a steeper slope than the portion nearer the base, and this is especially desirable in a bank of clay. It has to be kept in view that the material in any embankment is not absolutely compact until several years have elapsed from the time of it being deposited.

In order that a good toe be formed along the foot of the slope, the more solid materials in the cuttings should be deposited along the outer edge, and it is usual to strip the soil from off the area to be covered and lay it temporarily along and outside of the foot of the slope, where it will form a barrier for the deposited material and at the same time be conveniently situated for the subsequent soiling of the embankment. On side-lying ground it is desirable that a trench be cut in the solid ground along the foot of the slope against which the deposited material of the embankment will abut, and it is also necessary that longitudinal trenches be cut at intervals as has already been described, for the purpose of preventing slipping of the material; but any trenches so formed should not be executed for any lengthened period previous to the embanking material being deposited, as otherwise if wet weather intervenes the base of the embankments will be weakened rather than strengthened. The importance of taking away water from the foot of a slope and thereby ensuring the stability of the embankment at its most vulnerable point will be appreciated.

As in the case of cuttings, the formation of a good sward of grass is most effective in preventing damage by the percolation of rain or surface water, or by the action of wind on a newly formed slope, and no time should be lost in having the slope soiled. An embankment formed of clay can never be considered satisfactory until a good growth of grass covers the surface. In the case of sand or gravel water will pass through and drain itself off, but in the case of clay the water is retained and the clay will take a flat slope. A layer of good turf along the top of a slope will form a protection against the upper portion being damaged by the action of rain on a bank which has been recently soiled. While it is undesirable that the slopes of a high embankment should be soiled until it has been raised to the full height, it is better that they should at least be roughly dressed off to the finished batter as the work proceeds, and this is more especially necessary in the case of a clay embankment.

The upper surface of an embankment should also be impervious to water, and this is well obtained by the constant traffic which passes over it while the work is in progress, and as a precaution against water getting into the bank from the top the upper layer should consist of the more compact materials from the excavations,

and so that there will be no lodgment of water on the surface it should be finished off with a slight cross-fall from the centre to each side. In the interest of the stability of an embankment for a railway it is not desirable to make the formation too narrow so that there will be the less tendency for the top of the slopes to give way by reason of the traffic. When any settlement takes place after heavy rain or frost or thaw, any crevices that may be formed should be immediately restored with impermeable material.

While slips in an embankment, due to the material of which it consists, can in a large measure be prevented if proper provisions are taken, those due to the character of the ground on which the embankment rests are much less easily obviated. The site of the embankment may consist of moss, soft clay, or other similar material, and any weight brought on to it will tend to displace this material. When this soft stratum is of no great depth and the surface of it is level, or nearly so, no damage will result beyond the displacement of the surface, and the embanking material will soon find its bearing on the solid ground underneath; but if water should be present in the soft material, as will probably be the case, constant trouble may result if the ground has not been drained prior to the embankment being proceeded with. Any water on the site will cause the embanking material to spread out to a flat slope, and if clay or other similar material is deposited it will be turned into slurry, thereby causing a slip. The material on the site may be such (as in the case of some clays) that no amount of drainage will make it suitable for carrying an embankment, in which case it will either be necessary to drive sheet piling along the toe of the slope to prevent it spreading, or to excavate the material from under the site of the embankment and run it to spoil.

Where piling has been driven the pressure of the substratum has been known to shear off the piles at the level of the solid ground and carry them bodily forward for a considerable distance. The removal of the bad material to spoil will probably be an expensive operation, but it will certainly be the more effectual. In certain situations it may be impossible to thoroughly drain the site, and in such cases by depositing ashes, old slag, gravel, or other material that will not "run" on the top of the soft material on the site, the latter can be displaced and a solid foundation obtained, and, after the ashes or other materials have been raised to the level of the

original surface, the ordinary excavations from the cutting can be deposited.

In the event of the site being drained, the drains should be of a massive description and be laid either in diagonal trenches or square to the line of the bank, having an outlet into main drains formed along the outside of the slopes. These drains will be carried down to the solid ground, and those along the foot of the slopes will be of such dimensions as would also act as a retaining wall against which the embankment would abut. The material from the excavation of the drains could, if suitable, be burned into clinker and used for the drystone filling of the drains. If the depth of the soft strata on the site is such as to preclude the possibility of thorough drainage, the embankment would require to be

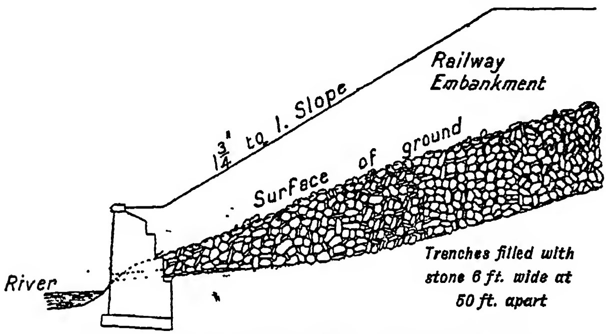



FIG. 68.—Slip in embankment on side-lying ground.

supported on fascines, as has already been described in connection with embanking over moss land. While the surface of the moss or soft material may be level, the firm ground underneath may be lying at an angle, and unless proper provision, such as has been referred to, is carried out serious slipping may result.

The embankment may require to be formed on side-lying ground of such a character that the material under the surface is in a state bordering on motion, and when any additional weight is applied slipping will take place. The unstable description of the ground may be due to the presence of water in the material lying under the surface, or to water acting on a greasy bed underneath, and the drainage of the site or the interception of the drainage from the adjoining land may be effective in converting the site into a good condition.

The following example will illustrate this point (Fig. 68). The ground on which the embankment was to be formed showed signs of slipping having taken place at a former period, and the stratum under the surface was of a very soft character and side-lying at an inclination of about 2½ horizontal to 1 vertical. Trenches 6 ft. wide were cut on the side-lying ground at right angles to the line of the railway at intervals of 50 ft., and were carried down to the solid ground underneath, which, in some places, was at a depth of 20 ft. below the original surface, these trenches being afterwards filled with large stones. Between these drains benches of 4 ft. wide by 3 ft. deep were cut at intervals on the sloping ground parallel to the line of the railway, and a heavy retaining wall was also built along the foot of the embankment, which, in addition to supporting the slope, acted as a training wall for the adjoining river. The excavated material from the line cutting was then deposited in regular layers and thoroughly consolidated between the drains and behind the walls.

In such cases as that last referred to, where there is a solid stratum of either rock or good material under the slipping material, it may be more economical to construct retaining walls alongside formation to support the railway, or it may be considered better to carry the railway on a series of arches. By adopting either of these expedients, the first cost may be more, but by reason of the subsequent maintenance of the earth slope being avoided the alternative schemes may be justifiable.

When an embankment is being formed on good ground a thorough examination of the surface should be made so as to ensure that there is no water coming to the surface from natural springs or drains which have not been properly intercepted. Any water that does appear should, if possible, be caught up outside the embankment slopes, but failing this it should be conducted by iron pipes or built conduits entirely clear of the operations. If the ground is side-lying, water may be percolating from the outcrop of a stratum, and it should be intercepted by a drain outwith the embankment, in a manner similar to what has already been described in connection with the protection of cuttings.

The following example will illustrate this point (see Fig. 69) :—

The stratum immediately underneath the surface soil was of a gravelly description, while underneath the gravel was clay at

varying depths. The water in the gravel was held up by the clay and made its appearance on the surface of the ground on which

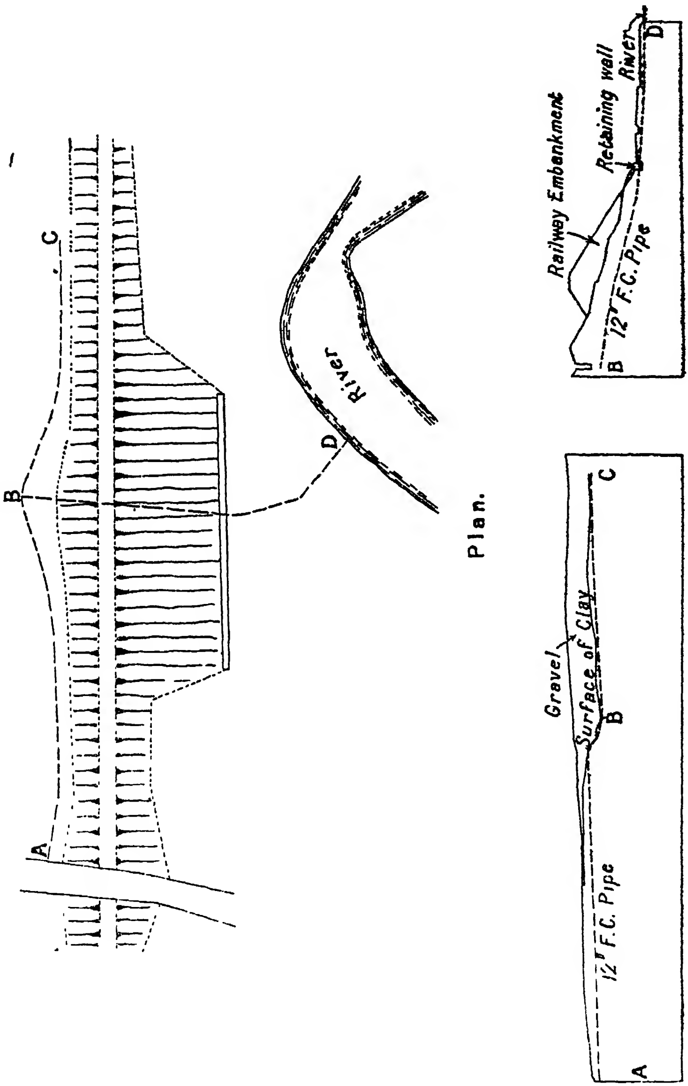



FIG. 69.—Intercepting subsoil water under embankment.

the railway was to be formed. With a view to intercepting this water, a drain was cut along and outside of the fence on the upper

side of the railway. The drain was in some places at a depth of about 25 ft. A pipe was laid in the bottom immediately on the top of the clay, the joints being left open and carefully packed round with broken stones. The trench was filled to the surface with stones, and all field drains intercepted were connected to this main drain. Owing to the irregular line between the gravel and the clay there had to be two outlets, one running parallel to the railway, the other carried underneath the embankment on the side-lying ground.

This latter drain consisted of cast-iron pipes supported with concrete blocks at the joints. A heavy retaining wall was built along the foot of the slope, and benches were cut in the side-lying ground, after which the embankment was formed. When the embankment had been brought to the full height, some water, which had not been diverted into the intercepting drain, appeared at places on the surface of the slope, and several minor slips took place. Four drains 7 ft. wide by 7 ft. deep were then carried up the slope of the embankment at intervals of about 30 ft. and filled with heavy stones to the surface, and the slopes were thereafter soiled and sown with grass seed and mixed with broom. A good sward was soon grown, and no further trouble was experienced.

In the construction of a railway or road in side-lying ground where the earthwork is partly in cutting and partly in embankment, great care should be observed to see that water from the cutting on the upper side should not be allowed to percolate under the embankment on the lower side, and it is necessary that the drainage of the adjoining land, as well as the drainage of the slopes of the cutting, should be properly attended to.

The remedial work required in the event of a slip in an embankment due to the material of which it is constructed consists of the removal of the water which has been the cause of the damage or the supporting of the slope in a manner somewhat similar to what has been described when referring to slips in cuttings. In an embankment, however, operations are not so restricted at the foot of a slope as they are along the formation line of a road or railway when the construction is in cutting, and it is thus unnecessary to remove the slipped material from the foot of the slope unless it is encroaching on adjoining property.

Surface slope drains or drystone counterfort walls carried down to the solid and a good strong toe wall built along the foot of the slope should be constructed as required. It is better that the slipped material should not be removed, but be allowed to remain at the angle of repose that it has taken, and if there should be intrusion on adjacent lands a wall may be required to support the lower portion of the slope or additional property may be necessary. Serious slipping in an embankment has been effectively stopped by loading the toe with heavy stones, thus arresting the outward movement.

Water getting into the heart of an embankment has frequently taken place by reason of fissures in the upper surface; this may be the cause of periodical slipping and will give constant trouble unless it is effectively dealt with. In such a case a drainage heading or series of drains driven into the bank would remove any water which had collected or was in the material, and it would also be necessary to remove part of the upper surface of the embankment and replace it by good material.

A case is reported where a bank 60 ft. high, formed of dry sand and gravel slipped by water appearing on the surface of the slope. The ballast and permanent way of the railway had been laid and, when investigation was made, the damage was traced to the manner in which the surface of the embankment had been executed. The formation of the railway had been formed to the usual ( for the purpose of draining off surface water, but the subsequent settlement of the embankment necessitated a greater depth of ballast being laid to bring the railway to proper level. For the sake of appearance the bench between the foot of the ballast and the top of the slope on either side has been made up with slag riddlings, which prevented the free drainage of the surface of formation, with the result that instead of the water running off the slopes it was held in a hollow under the rails, thereby finding its way into the sand and gravel and causing the slip.

Embankments have been known to slip after a number of years through water, which had no means of escape, having collected in the heart of the bank, and on a drain being formed to the seat of the trouble the water found an outlet and the slipping ceased.

Slips due to bad material being deposited in embankment are sometimes very troublesome, and there are cases on record where

an entire bank has had to be removed and run to spoil. The material of which it was constructed appeared to be quite good when deposited, but after wet weather set in it was converted into slurry.

If the slip should be due to unequal settlement of the embanking material, the fissures which are formed on the surface should be closed up, otherwise the embankment may be completely rent in two. In such cases, after settlement has taken place, the upper portion of the embankment for several feet in depth should be removed for the full width, both of the stable and unstable material, and the bank thereafter brought up to its original level by means of ashes or other dry material, so as to ensure that any load afterwards applied to the upper surface will be equally distributed over both parts of the embankment underneath. When the site of the embankment is unsatisfactory and the preventive measures already suggested have either failed or have not been properly executed, serious slipping may result. Embankments have been known to move for many years after they were constructed, in some cases leading to their ultimate abandonment.

## CHAPTER VII

### MAINTENANCE OF EARTHWORK

The more thoroughly the work of constructing the railway is carried out the less will be the subsequent cost of maintenance.

In the preceding chapter the means taken to prevent and remedy slips were considered. It was pointed out that the greater number of slips were due to the presence of water, and the necessity for diverting water away from cuttings and embankments, or of leading it away in such a manner as would prevent damage, was emphasised. It is necessary, however, that these preventive and protective measures should be kept under constant observation, and that so soon as any interruption of the functions for which these special works were carried out is observed, immediate steps be taken to remedy matters.

The maintenance of railway works is always greater the first year or two after the works are completed than during subsequent years.

Special inspection should be made of cuttings and embankments, more especially the drainage works, during wet weather or after periods of melting snow or abnormal discharge from water-bearing strata, when the various drainage works will be fully taxed, and this inspection should be carried out in a most thorough manner, so as to ascertain what, if any, additional works are necessary and what repairs require to be executed. In the case of open ditches it will at once be seen where there is any interruption of the regular flow, and the ditch can be cleaned out; but in the case of pipe drains, or piping laid in the bottom of stone pitching (or "beaching"), an obstruction may not be detected until there is indication of such on the surface, either in the form of a discharge of water or by damage to the slope or surface of the ground.

The maintenance of the permanent way in first-class condition

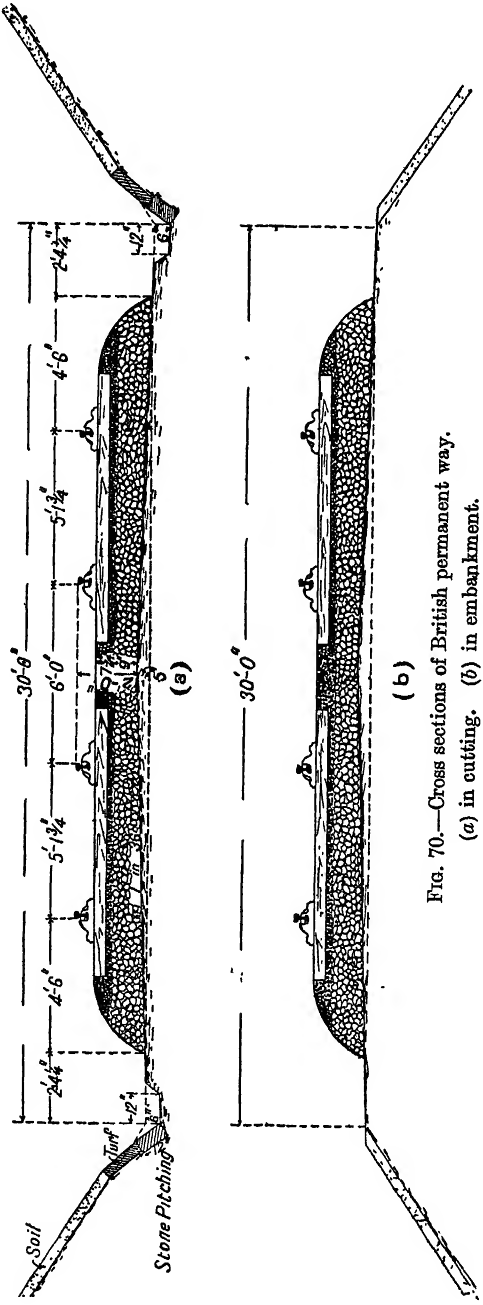



FIG. 70.—Cross sections of British permanent way.
(*a*) in cutting. (*b*) in embankment.

is one of the principal duties of the Engineer, and to obtain the best results perfect drainage of the formation is essential.

Water falling on the railway or draining on to it should be removed as speedily as possible, and the railway works should be designed with this in view. The surface of the formation in both cuttings and embankments should have a camber or cross-fall from the centre to the sides so that water passing through the ballast will be shed off, and in cuttings side drains or open ditches should be provided for the removal of water both from the formation and from the railway slopes. Fig. 70 shows typical cross-sections of British main line permanent way.

The ballast under the sleepers is regarded as the foundation of the permanent way; but the real foundation is the material on which the ballast rests, and if it is unsatisfactory the whole object of having good ballast is defeated. A good foundation under the ballast is of equal importance to the ballast itself. It is thus necessary that the material immediately under the ballast he kept thoroughly drained, and this is effected by side drains or open ditches.

If water is allowed to collect under the sleepers, or if the material under the sleepers retains water, the soft wet material will very soon be converted into mud, and will be squeezed through the ballast. The result will be that the life of the sleepers will be very considerably reduced, the fastening of the chairs to the sleepers will be rendered ineffective in a short time, and the permanent way generally will be seriously impaired.

The material under formation may be of such a description that it cannot be drained, and any water passing through the ballast into it converts it at once into slurry. In this case it will be better to remove such material to a depth of 2 or 3 ft., or deeper if necessary, and replace it by old slag or spent ballast, ashes, or other material that will not obstruct the drainage.

So far as the ballast of the permanent way is concerned it should consist of good hard slag, broken whinstone, granite, or other material which will permit of free drainage, and at the same time give a solid bed for the sleepers.

Good drainage and good ballast are essentially necessary for first-class permanent way.

Reference was made in the previous chapter to the damage done

by making up the sides of an embankment—where additional ballast was necessary to bring the railway to proper level—with earthy material so as to have a neat and tidy appearance, with the result that instead of having a fall from the centre to the sides, there was actually a water channel down the centre of the railway, which ultimately found an outlet on the face of the embankment and caused a slip. It would have been better to have left the edges of formation low, although they might have had a slightly ragged appearance, rather than interrupt the free drainage of the formation. Neatness in maintaining the railway is an indication that the work is also being efficiently executed, but if those who are responsible for the maintenance of the permanent way do not thoroughly appreciate the importance of good drainage, their efforts in maintaining a neat formation will be entirely ineffective.

The object, so far as the drainage and width of a cutting are concerned, is to bring the condition of the roadway as near as possible to what exists in an embankment where there is free drainage and the railway is in the open.

The formation of a railway in cutting should be as wide as possible, so as to obtain proper drainage, and also to get the benefit of the drying effect of wind and sunshine. It is a mistaken policy to cut down the width of formation at the expense of the maintenance. natter has already been referred to in Chapter I, page 4.

the drainage of cuttings an open channel is preferable to a closed pipe, as it can be easily cleared of any obstruction. When the gradient of the railway is flat and the flow of water sluggish, an open channel is easily obstructed by debris, leaves of trees, washings off the slopes, and stones from the ballast, and any interruption of the flow will tend to weaken the support of the ground under the sleepers, and also to undermine the foot of the slope of the cutting. For this reason, a pipe would be used in preference to an open channel on a flat gradient. Apart from the question of the gradient, it may not be possible to construct an open channel on account of the soft description of the material, in which case a pipe would be laid.

When a ditch or open channel is provided it should be formed along the foot of the slope, one side of the channel being the toe of the slope. The channel would be about 1 ft. to 1 ft. 6 in. wide by 6 to 9 in. deep. If the material in the bottom of the cutting is

of a firm description the sides would be able to support themselves; but, so as to form a toe for the bottom of the slope of the cutting, a 12-in. depth of stone pitching, with a double layer of turf 1 ft. 6 in. broad laid on the top, should be placed alongside the channel. Where the material is unstable, the channel would be lined with stones on both sides. In the case of cuttings over 15 or 20 ft. deep where a large volume of water may have to be dealt with, it is usual to have a low drystone wall along the foot of the slope, with the channel formed immediately in front.

When, instead of an open ditch, a pipe is laid alongside formation, the top of it should not be less than 9 ins. below formation, and so that there will be free drainage into it, and that no water will get out of it to the damage of the ground underneath, the joints should be cemented or formed with puddle clay to the level of the horizontal diameter, while the upper half of the joints should be left open. The filling in of the trench should be carefully and firmly packed up to the same level as the sealed half of the joints of the pipes with clayey material. Above this level the joints should be carefully surrounded with broken stones and the trench filled to formation level with broken stones. The upper surface at formation level should be finished off with slag, or broken stone screenings, thereby ensuring that any water running off the permanent way or off the slopes will drain into the pipes. The pipe gratings should be placed at intervals along the edge of formation. Inspection chambers should also be provided on the line of the pipe at inter about 80 yards, and to allow for any stoppage in the flow pipe cross pipes connecting both sides of formation should be laid at every second or third inspection chamber.

It should be kept in view that the drainage works in a cutting are as much for the purpose of keeping the material under the railway in a good condition as for the removal of water which falls on the surface.

It is very important that the slope of the open channels or pipes in a cutting should be as steep as possible as, if the water which has been collected into them is not expeditiously removed, considerable damage may result. In long cuttings the water-course may be made slightly steeper than the railway cutting on one side of formation, and connected at intervals by cross pipes to the drain at the foot of the opposite slope. Connections should be made to the nearest

outlet, and the water conveyed in properly formed ditches or in pipes entirely clear of the railway embankment. If it is merely allowed to discharge on to the ground and run along the foot of the embankment serious damage may result by eating away the toe of the slope, or what may be very much worse, the water may find its way underneath the embankment.

For the purpose of obtaining a fall for drainage, it is better that the railway in cutting should be constructed on a gradient.

The Pennsylvania Railroad Company, America, has given considerable attention to the question of maintaining the road-bed at high standard. A part section of their cutting is shown at Fig. 71. The distance from the outer edge of the ballast to the foot of the slope is 5 ft. 6 in., and the side ditch is formed by having an even fall from the ballast to the foot of the slope of the cutting, the

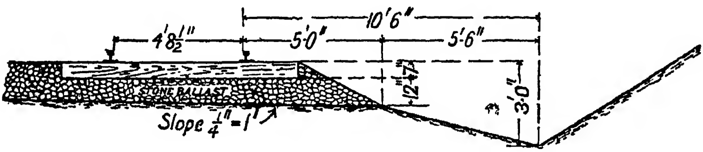



FIG. 71.—Part cross section of Pennsylvania railroad, America.

bottom of the ditch being 1 ft. 5 in. below the bottom of the ballast at the edge. The slopes are protected from erosion by being turfed, and, where necessary, drystone toe walls are built. With so great a distance from the ballast to the foot of the slope, no damage results to the ballast even with the railway on a very flat gradient. The whole object of the greater width is to obtain good drainage, with a view to keeping down the cost of maintenance. The cost of maintenance is, no doubt, considerably reduced, but the extra cost of construction is great. The cost of the additional land required for the greater width has also to be considered.

Reference has been made to the importance of having a good sward of grass on the slopes of cuttings and embankments. Having got this, it is necessary that it be kept in good condition by having it regularly cut or burned. In open country where passing through agricultural land, it is a common practice to let the adjoining farmers have the grass off the slopes for a nominal rent, conditionally that they keep the slopes regularly cut. Where the Railway Company's own men attend to the slopes it is usual to burn the grass,

and this, while keeping the grass short, also provides a manure which strengthens the roots.

The ends of all culverts should be regularly cleared of all debris, branches of trees or other material which may have collected in the culverts, and which cause stoppage or interruption to the regular flow of the stream.

To protect the railway where in cutting from being blocked by snow drifts it is usual to erect sleeper fencing on one or both sides of the line where considered necessary. An additional line of sleepers placed about 15 ft. distant would be a further protection.

In countries subject to very heavy falls of snow endeavour is made to have the line of railway altogether in embankment, but where cuttings are unavoidable it is usual to protect the line of railway from being blocked by having snow sheds erected where the blocks are likely to take place. These sheds consist of open framework covered over either with wood or corrugated iron sheeting.

In rock cuttings where stones are likely to become detached by reason of frost and subsequent thaw and which would cause an obstruction to the railway traffic, an arrangement has been successfully adopted whereby engine drivers are warned of an obstruction. A series of wires on telegraph poles is carried along the side of the railway adjoining the cutting, and connected with a signal on the railway which normally stands at "clear," and in the event of the wires being broken by falling rock the signal at once rises to "danger."

# CHAPTER VIII

## CONDITIONS AFFECTING THE COST OF EARTHWORK

In Chapter I reference was made to the various matters to be considered when preparing the estimate of cost of an earthwork undertaking. It is now proposed to discuss in some detail the points which affect the actual expenditure in the practical work involved. These vary very considerably under different conditions; but, briefly stated, they are:—

(1) The cost of labour.
(2) The character of the materials to be excavated.
(3) The facilities for removal of the excavations or convenience in obtaining the embanking material.
(4) The prevailing weather conditions when the work is in progress and the time within which the work is to be executed.

It may appear superfluous to state that the financial success of an earthwork undertaking very largely depends upon the efficiency of the control of the operations. So much, however, attaches to the management that it is necessary to emphasize this point. A thorough knowledge of how to make the very most out of a job can only be obtained by a close acquaintance with constructional work and this, along with the qualification of handling men and a quick and clear appreciation of the difficulties and emergencies attendant on such work, combine to form the superintendence which is essential for obtaining the best results.

The cost of the work can very materially be reduced by having skilful, resourceful, and experienced men in charge. These remarks apply equally to the manager, foremen, and gangers in charge of the various squads of men distributed over the work. This is specially necessary in the construction of earthwork on which the men engaged are for the most part drawn from unskilled labour.

When large numbers of men are engaged and are exposed to changeable weather, working frequently under most adverse conditions, the proper housing of them is an important consideration. Attention to their personal comforts will more than anything else create a good feeling, with correspondingly satisfactory results in the execution of the work.

With a view to expediting the output from cuttings or the forming of embankments the Contractor may find it convenient to encourage the "gangers" who are in charge by paying them bonuses on results, after the number of wagons or cubic yards handled *per diem* exceeds a certain number. A similar object is attained by sub-letting the labour to the "ganger," thus giving him a financial interest, however small, in the work.

The contractor will find it to his advantage to have a systematic cost made every week or fortnight throughout the whole course of the operations, from which he will see whether the work is being profitably and economically executed.

For this purpose he should have a costing Engineer, whose duties will be to calculate the quantities of the several items of work and collaborate with the timekeeper at the works, who should furnish him with the actual expenditure under each heading of cost.

The diagram (Fig. 72) shows a form of cost statement suitable for the several works met with in an earthwork contract.

In the case of the cuttings the statement will show the total quantity of material removed over a period of a week or fortnight, together with the actual expenditure for that period and the cost per cubic yard can thereby be obtained.

Alongside of this cost there is shown the rate in the Contract Schedule, and the Contractor can see at a glance whether the work is being carried out at a profit or loss.

The statement also shows separately the cost of the labour, plant, and stores per cubic yard, and from this information he should be able to locate any excess expenditure.

Under the heading of "Plant," the amount in respect of wagons, cranes, locomotive engines, steam diggers, and other heavy plant should be computed on the basis of the cost being distributed uniformly over a period. Two years might be taken, and on this basis, if a locomotive should cost £2000, the cost each fortnight exclusive of coal and other stores would amount to £38 9s. 3d.

## ACTUAL COST OVER A PERIOD OF ONE YEAR

| Date. | No. of Days. | Character of Materials. | Method of Excavating. | Method of Haulage. | Depth. | Lead. | I. Labour. | II. Plant. | III. Stores. | Total. | Quantity. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Feet. | Chains. | Pence. | Pence. | Pence. | Pence. | Cub. yds. | |
| August | 14 | Boulder Clay | Steam Digger | Locomotive | 18 | 28 | 7·5 | 1·0 | 1·0 | 9·5 | 8830 | |
| " | 14 | " " | " " | " | 12 | 30 | 8·2 | 1·1 | 1·1 | 10·4 | 3530 | |
| Sept. | 14 | " " | " " | " | 10 | 31 | 12·7 | 2·0 | 1·3 | 16·0 | 1580 | Travelling digger back. |
| " | 14 | " " | " " | " | 6 | 29 | 18·1 | 2·9 | 1·7 | 22·7 | 1000 | Dressing slopes and excavations, v ry wet. |
| Oct. | 14 | " " | " " | " | — | 27 | 18·1 | 2·8 | 1·5 | 22·4 | 1320 | do. |
| " | 14 | Gravel and Sand | " " | " | 4 | 30 | 10·7 | 1·6 | 1·2 | 13·5 | 2350 | Dressing slopes and removing slips. Wet weather. |
| Nov. | 14 | Gravel and Clay | " " | " | 8 | 33 | 13·8 | 2·8 | 1·5 | 18·1 | 1460 | do. |
| " | 14 | " " | " " | " | 7 | 36 | 10·4 | 1·8 | 1·5 | 13·7 | 2120 | Stripping soil, removing slips, and laying service roads. |
| " | 14 | " " | " " | " | 9 | 39 | 10·4 | 1·9 | 1·6 | 13·9 | 1970 | Laying temporary railways. |
| Dec. | 14 | " " | " " | " | 11 | 41 | 15·3 | 8·3 | 3·4 | 22·0 | 1310 | do. Wet weather. |
| " | 14 | " " | " " | " | 15 | 42 | 11·0 | 1·9 | 3·2 | 16·1 | 1422 | do. |
| Jan. | 14 | Gravel and Sand | " " | " | 31 | 75 | 8·0 | 1·4 | 2·0 | 11·4 | 3783 | do. |
| " | 14 | " " | " " | " | 34 | 76 | 6·5 | 1·1 | 2·1 | 9·7 | 4896 | |
| Feb. | 14 | " " | " " | " | 35 | 77 | 6·2 | 1·2 | 2·2 | 9·6 | 4963 | |
| " | 14 | " " | " " | " | 32 | 79 | 6·2 | 1·2 | 2·0 | 9·4 | 5077 | |
| March | 14 | " " | " " | " | 36 | 81 | 4·9 | 0·8 | 1·8 | 7·5 | 7237 | |
| " | 14 | " " | " " | " | 36 | 84 | 4·7 | 0·9 | 1·6 | 7·2 | 6642 | |
| April | 14 | " " | " " | " | 36 | 84 | 4·9 | 1·0 | 1·7 | 7·6 | 6376 | |
| " | 14 | " " | " " | " | 36 | 84 | 4·4 | 0·9 | 1·5 | 6·8 | 6915 | |
| May | 14 | " " | " " | " | 36 | 84 | 5·6 | 1·2 | 1·6 | 8·4 | 5216 | |
| " | 14 | Sand | " " | " | 15 | 84 | 8·2 | 1·4 | 1·5 | 11·1 | 4523 | |
| " | 14 | " | " " | " | 17 | 87 | 7·9 | 1·1 | 1·9 | 10·9 | 2886 | |
| June | 14 | " | " " | " | 19 | 90 | 6·3 | 1·0 | 1·5 | 8·8 | 6042 | |
| " | 14 | " | " " | " | 21 | 93 | 6·7 | 1·2 | 1·6 | 9·5 | 5236 | |
| July | 14 | Gravel | " " | " | 17 | 96 | 8·2 | 1·7 | 2·0 | 11·9 | 3688 | |
| " | 14 | " | " " | " | 16 | 98 | 6·7 | 2·1 | 1·9 | 10·7 | 2937 | |

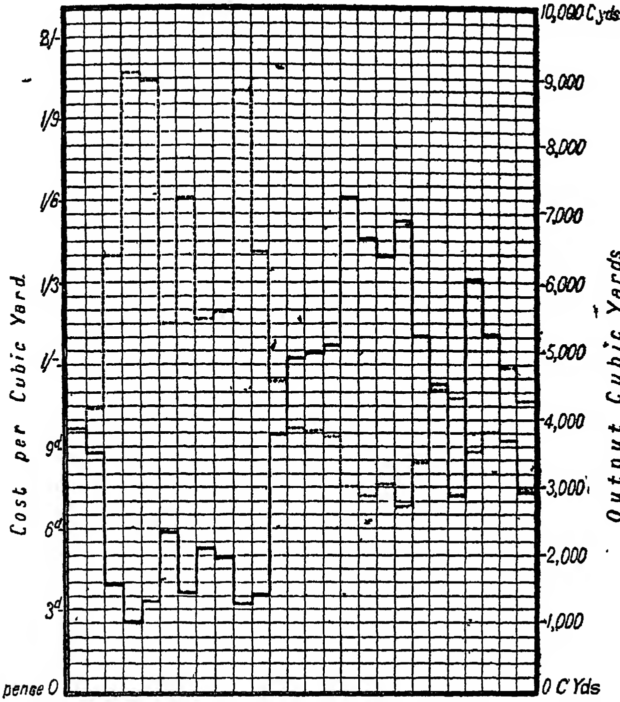
NOTE.—The work was in a single line cutting, but the above record refers to operations conducted at a level where there was comparative freedom for the excavating work being executed.

FIG. 73.—Detailed statement of cost and output of railway cutting.

Total output for whole year totalled nearly 100,000 cubic yards.

The statement will also show the actual cost of concrete, masonry, and brickwork in building culverts, etc., and as in the case of cuttings any excess expenditure should be investigated.

The importance of having these costs prepared will be more fully appreciated when reference is made to Fig. 73, which gives




*Hard dotted line represents cost per cubic yard.*
*Hard full line represents output in cubic yards, each fortnight.*

FIG. 74.—Diagram of cost and output of railway cutting.

particulars obtained from the cost statements of output and relative cost of a cutting including disposal in an embankment, extending continuously over a period of twelve months. The material in the cutting consisted of sand, or sand and gravel, and was deposited in embankment at an average distance of about a mile from the cutting.

Fig. 74 gives the same information diagramatically, and clearly

shows how, with a large output, the cost per cubic yard is very much less than what it is when the output is low.

The two best months' work was in March and April, the average output during that period being 615 cubic yards per day at an average cost of 7·3d. per cubic yard. The average output over the whole year was 350 cubic yards per day at an average cost of 10·2d. per cubic yard. These costs include depositing in embankment. The work referred to was executed previous to the outbreak of the European War in 1914, when navvies' wages averaged about 5d. per hour, and consequently do not represent the cost of the work at the present time.

A saving of ½d. per cubic yard in the cost of excavations spread over 1,000,000 cubic yards represents over £2000, and this will repay the Contractor the additional expenditure incurred in having the costs made. In work of this description constant vigilance is necessary to ensure the most rigid economy.

The Engineer, for his own information and for that of the promoters, should be fully informed as to the progress and cost of the works as the operations proceed, and this can best be seen in a diagram.

Information of this description shown on a diagram indicates at a glance whether the operations are being satisfactorily executed, both as regards cost and progress.

As regards the cost of labour, the fluctuations of the labour market may largely affect the cost of the work, a small increase or decrease of the rate of wages being sufficient to very materially influence the total value. If wages are low when the work is being tendered for, the Contractor, keeping in view a probable rise during execution of the works, may found his estimate on the basis of a higher rate, but by so doing he may reduce his chance of obtaining the contract. This difference will, of course, be more apparent in work on which the greater part is executed by hand labour rather than on that where steam diggers or other heavy plant are used and where the quantity of material handled is considerably greater per man employed during a given time.

In connection with the character of the materials to be excavated, while the classification of "soft" and "rock" may be sufficient on which to prepare a Contract Tender, these two designations very inadequately describe the various kinds of material that may be

met with, and in many cases misrepresent the characteristics of them so far as their removal from a cutting or placing in an embankment is concerned. A dry sand cutting is the simplest and least expensive to excavate, but, if there should be water in the sand, the removal of it may be equally as costly and much more troublesome to deal with than solid rock.

A tough boulder clay is the most difficult of "soft" materials to excavate, but certain clays or clay with sand are very troublesome if water is present in sufficient quantity to convert it into "slurry."

The cost of the work is thus largely dependent on the quantity of water met with and the effect of water on the materials to be excavated.

If clean, sharp sand, gravel, or solid rock is met with in the cuttings, it will have a commercial value in so far that sand and gravel can be used for concrete, freestone, or granite for building purposes, and freestone or whinstone for road making and pitching slopes of streams and water-courses.

In the case of excavations in solid rock, if it is such that it can be put to any of the uses referred to it will generally be advantageous. The time under which the work is to be executed may, however, necessitate its removal by the usual methods of blasting instead of by quarrying as would otherwise be done. A good rock cutting is a decided asset, and the cost of excavation should be credited with its value, provided it can be used. If there should be a large quantity of rock to excavate, the removal of it may be [illegible] to the completion of the work, and it may consequentl[illegible] necessary to expedite operations by carrying them on at several points by sinking trenches and driving headings at considerably greater outlay than would be incurred if the work can be proceeded with from open ends.

It may be a convenience to lay an overland service route clear of the cutting to link up the lines of communication between the works on one side with the works on the other side, and thereby give greater freedom in excavating the rock cutting.

In both soft and rock cutting, where it is not possible to have free drainage from the working face, the unit price will be increased by the expense of the pumping necessary to keep the excavations free from water.

Considerable importance attaches to the facilities for removal

of the excavations from a cutting. It is in this connection that the work of a canal, dock, or other open excavation is so materially different from the confined space generally anticipated in a stretch of railway, road, or similar work.

As has already been pointed out, it is necessary, in order to obtain sufficient width to excavate a cutting for a single line of railway by means of a steam digger, to carry on the operations at a level of about 4 ft. above the level of formation. The bottom portion has thus to be taken out by hand at a greater unit cost. In a double line of railway work can be carried on at formation level with better facilities for bringing forward and removing the muck wagons, and, if there is greater width, as in the case of a canal, the accommodation for wagons will be still better, with consequent less delay or stoppage of the operations. When, as is sometimes done in canal excavations, the material is deposited on land immediately adjoining the cutting, any delay will be due to a break-down of the digger or excavator, and any cessation of operations will be reduced to a minimum, and the unit cost will also be a minimum.

As already stated, the cost of the work is largely dependent on the relative positions of the cuttings and embankments and the length of the "lead" from the cutting to the embankment or other place of deposit.

It is, of course, a convenience if the material can be run down grade to embankment.

In the event of it being necessary to run material to spoil embankment the cost will be increased by the rental of the land on which the spoil embankment is situated and also the restoration of the surface.

The conditions of the weather and the season of the year during which the work is being carried out sometimes very seriously affect the cost. It has already been suggested that practical operations should be commenced during the early springtime, so that full advantage may be had of the more favourable weather and long day of the summer season. In work extending over a period of years every effort should be made to get as much done as possible in good weather, and during unfavourable weather conditions operations should if possible be curtailed or temporarily suspended.

When work is carried on in wet weather not only is the cost of the excavations increased, but the material when put into embankment, being in a sodden condition, may cause serious slipping at

a subsequent date, necessitating considerable expense in repairs. While the men usually employed are only paid during the time they are actually engaged, there are "oncost" charges for managers, engineers, foremen, etc., as well as the interest and depreciation in value of the plant in use, to be met whether the work is being carried on or not, but it is better to stop operations for a time if the circumstances will permit.

Under certain conditions the actual cost per cubic yard of a cutting taken out by a steam digger may not be less than that excavated by hand, but the larger output and the ensuring of the work being executed in favourable weather may justify the use of the digger.

The effect of weather conditions on the cost of the work and the advantage to be gained by making the most of the good weather both as regards the reduced cost and the larger output has already been referred to.

Considerable expense is sometimes incurred in maintaining service lines of railway when crossing soft ground, by having to make up subsidences with ashes or otherwise.

The time within which the work is to be executed may require that operations be unduly pushed, but before tendering a Contractor should satisfy himself that the time allowed under his Contract is sufficient to enable him to execute the work in a manner corresponding with the amount which he has stated in his Tender. The time allowance may be altogether inadequate—no matter what the mode of procedure may be, and not infrequently Engineers make the mistake of not giving this point sufficient consideration. As a common example, the greater part of the excavation of a railway may be confined to one cutting, and the more economical method might be to take it out by means of one or two steam diggers, working from the lower end of the cutting; but, in order to complete the work within the Contract Time, it may be necessary to proceed with the excavations from both ends simultaneously, and the probability is that at some points it may be necessary to excavate against the gradient, necessitating pumping and additional steam power at greater cost. If the same quantity of material were distributed over two or three cuttings where each could be working independently of the other, the cost would be much less and the work executed in a shorter time.

# CHAPTER IX

## SPECIFICATION

The execution of all engineering works of importance is carried out under Contract. The Contract Specification consists of " General Clauses " for the protection of the rights of both parties to the Contract. These are, for the most part, of a legal character, and there are in addition " Works Clauses," which are descriptive of the class of work and the manner in which the Engineer wishes it carried out.

The Specification is framed by the Engineer and forms one of the Contract documents signed by the Contractor, and is binding on him for the due fulfilment of the Contract.

In the preparation of the Specification the Engineer should be careful to ensure that what he wants is clearly brought out, and that he is neither asking for more than he expects to get, nor less than is essential for what he will afterwards insist on having. The language should be perfectly clear and of the simplest description, having only one interpretation, so that there may be no subsequent ambiguity as to the meaning attached thereto. The Engineer must himself understand his Specification as otherwise he cannot complain if the Contractor fails to understand it.

In no constructional work is a Specification more necessary than in a Contract involving the execution of earthwork, and there is probably no other class of work where the Specification is more frequently departed from. There has probably been more controversy over questions of earthwork than any other operations which fall to be dealt with by an Engineer.

The essential points for the " Works Clauses " of an earthwork Specification have already been revealed in describing the various constructive operations, and in the present chapter it is proposed only to refer briefly to a few of the points of difference which frequently arise in carrying out Contract work.

Prices are cut so keen in making up a Schedule that it is not to be wondered at that a Contractor should claim to be paid for the slightest departure from the terms of the Contract, and at times play on the sympathies of the Engineer to get something more than a rigid interpretation of the Specification allowed.

A frequent cause of difference has reference to the classification of excavations. This matter has already been referred to under the heading, "Investigations as to Strata," at page 17, and "Cost of Earthwork," at page 139.

It is usual to have earthwork material classified in a Contract Schedule with the two descriptions, "soft" and "rock." A common form of Specification reads, "All material other than solid rock will be paid for as ordinary 'excavation,'" and, "Nothing will be paid for as rock except solid sandstone, solid limestone, or solid whinstone." It might at first sight seem better to have a middle classification of "soft rock" in cases where large quantities of material have to be removed, this term to include such material as fireclay or other shaley clay, hard boulder clay or close-bound gravel, which are only capable of removal by means of a pick and which not infrequently requires to be loosened by blasting. Materials of this description are more difficult to remove than sand, loose gravel, clay, or earthy material, and it is the classification of materials of this description that raises the point of difference.

Some Engineers ask Contractors to give an overhead rate to cover all classes of material which he may meet with, and, while this may get over the difficulty of classification, it is better that the Engineer in calculating his quantities should have a distinction between "soft" and "rock," and the writer is of opinion that no advantage is gained by having an intermediate class.

Part of the soft material may be very difficult to excavate, or it may contain a large volume of water, which makes it much more costly to remove than if the cutting was dry; but the Contractor should carefully consider these matters with the information obtained as to strata supplemented by minute investigations on the ground and any additional particulars he may obtain as to the probable quantity of water likely to be met with when carrying out the work. He must also consider what means will require to be taken to intercept the water and direct it clear of the operations, and price his Contract Schedule accordingly.

This raises the question of the accuracy of the preliminary investigations which has already been fully dealt with in Chapter II. The quantities of material separated into "soft" and "rock," stated in the Contract Schedule, are prepared from this preliminary information, and if those quantities have been imperfectly estimated, or if any of the material to be excavated has been wrongly described, the cost of the work may be largely exceeded and the Contract time for completion may be inadequate.

As already stated, it is customary for the Engineer to have trial bores put down on the line of the railway or site of the works, and the Contractor will have the benefit of the information so obtained. The journal of these bores should not, however, form part of the Contract Documents, and the Contractor will require to take the risk of the materials in the excavations turning out different from what he may have expected. This matter is also referred to in Chapter IV, page 47.

In connection with bridges, culverts, etc., it is important that these be detailed as fully as possible in the Contract Schedule. All culverts require to be constructed previous to the railway embankment under which they are carried being formed and the greater number of bridges, both over and under the railway, will also require to be constructed before the railway is formed up to them. Consequently, the materials for these works may require to be taken over fields and inferior roads at greater cost than would be the case if the points on the line where these special works are being constructed were more easily accessible. The Contractor may have a "flat" rate for masonry, concrete, etc., no matter where the works are to be situated on the contract, but it is better that he should have the opportunity of pricing the items for each work separately, and he cannot afterwards have any grounds for claim on account of the inaccessibility.

Any departure from the original schedule will, in all probability, add to the cost of the work, and that in a greater proportion than the increased quantities represent.

Questions relating to damage by water not having been properly intercepted alongside of cuttings and embankments, and to the operations not having been executed in such a manner as to prevent the occurrence of slips, frequently arise. It is usual to ask a Contractor to state a sum for dealing with slips, which sum is

over and above payment for the construction of such intercepting catch-water and slope drains as the Engineer considers are essential for the construction of the works. The sum stated by the Contractor in his Schedule may be altogether inadequate to cover the cost of slips that will occur under the best of management, but the Contractor is liable in any expense thereby incurred. In carrying on his operations the Contractor will require to execute such temporary drainage and other contingent works as are necessary in his own interests, but if the operations are under proper superintendence, the risk of damage by reason of water will be very largely reduced.

The necessity for executing the drainage work of the adjoining lands previous to the cuttings and embankments being commenced, and the importance of timeously dealing with water which appears in a cutting, have already been referred to in Chapter VI.

It is usual to stipulate in the Specification a date before which the works are to be completed, and, in fixing the Contract Time, the Engineer should put himself in the position of the Contractor and consider how the work is to be done within the time which he proposes to stipulate. The value of the work is not necessarily the measure of the time for completion, neither is the total volume of material to be excavated. There may be 250,000 cubic yards of excavation to remove, and if this quantity is in several cuttings and can be proceeded with simultaneously at various points the work will be more speedily executed than if the whole of the material is to be removed from one working face. The removal of the excavations from a cutting may depend on the construction of a tunnel, viaduct, bridge, or other work, and this should be kept in view in fixing the Contract time. As has already been stated, the time of the year in which the work is executed will also largely affect the time taken to execute.

Endeavour should be made, as far as possible, to avoid time account work, and any extra work should, wherever possible, be paid for at Schedule rates, or at rates proportionate to the Schedule rates for similar work. There is always a temptation on the part of the Contractor to unduly extend work when he knows that he will be paid for it by " time and lime."

The importance of employing experienced men who are skilled in this particular class of work has already been referred to, and,

in many cases, a Contractor loses by not having the best of men to supervise his operations, and this is very frequently the cause of difference between the Engineer and the Contractor. If he should not have the works properly managed, the most successful methods will not be adopted, or by adopting particular methods he may be compelled to execute certain parts of the work in winter or during adverse weather conditions, and consequently the works are uneconomically carried out and at excessive cost.

The Contractor requires to have sufficient capital or have the necessary financial support to ensure that the works will not suffer for want of the most suitable plant. It is usual to specify that "the Company (or Corporation) do not bind themselves to accept the lowest or any Tender." In advising his clients the Engineer should be satisfied that the Contractor whose Tender he recommends should be accepted is not only financially sound but that he is thoroughly capable of handling the Contract. For an earthwork contract, probably more than in any other engineering undertaking, the successful Contractor should be a specialist in this class of work. He may have sufficient capital or financial support, but if he is not accustomed to the work he is not a success and the result reacts both on the Contractor and on the promoters for whom the work is being executed. If, on the other hand, he knows his work but lacks the capital, he is hampered through not being able to employ the most suitable plant.

The contract will probably include steelwork for bridges, and the Engineer will require to be satisfied that it can be properly executed and timeously supplied. If the steelwork is not erected at the time when it is wanted, the Contractor may be put to the expense of providing temporary trestle bridges or constructing other temporary works at considerable expense.

Before recommending a particular Tender, the Engineer should be satisfied that the Contractor can execute the work for the amount of his Tender. If it is quite apparent that the Contractor is going to lose by the contract, it is better that the promoters should not give him the work to execute, as the work will most probably cost the promoters more in the end than they would otherwise have paid if the Schedule had been correctly priced.

The Contract will include for maintaining the whole works for a period after completion, generally twelve months, and the Contract

Schedule should have an item for maintenance for that period. The Contractor may not enter a price opposite this item, or the sum which he states may be inadequate, in which case it is assumed that the other items in his Schedule either in whole or in part allow for the cost of maintenance. In the case of the greater number of engineering works, the cost of maintenance may be small, but in the case of the earthwork of a railway the cost of proper maintenance may be a fairly large sum. This maintenance includes the repairing of slips and soiling of slopes which may have been damaged by weather, the cleaning of ditches, and the bringing to proper level any embankments which may have subsided, and the leaving of the work in an entirely finished condition. The cost of maintenance is largely influenced by the manner in which the several works have been executed. This matter has already been referred to in Chapter VII.

The points above referred to are sufficient to indicate the difficulties attached to the Engineer's duties where he wishes to be absolutely fair to the Contractor, while at the same time jealously guarding the interests of his clients who have to pay for the work.

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